Recibido
26/08/2023

Aceptado
11/09/2023

Grafeno y coltán: oportunidad de desarrollo para la industria electrónica en Colombia

Graphene and coltan: development opportunity for the electronics industry in Colombia

Hernán Paz Penagos [1]
Esteban Morales Mahecha[2]
Diego Arturo Coy Sarmiento[3]

Cómo citar:
Paz H., Morales E., Coy A. (2023). Graphene and coltan: Development opportunity for the electronics industry in Colombia. *Vía Innova, 10 (1), 69-94.*
https://doi.org/10.23850/2422068X.5835

1 Associate Professor, University Escuela Colombiana de Ingeniería Julio Garavito, hernan.paz@escuelaing.edu.co, Bogotá D.C., Colombia. ORCID ID: https://orcid.org/0000-0002-2692-1989

2 Undergraduate student in Electronic Engineering, University Escuela Colombiana de Ingeniería Julio Garavito, esteban.morales-m@mail.escuelaing.edu.co, Bogotá D.C., Colombia.

3 Master's Student in Electronic Engineering, University Escuela Colombiana de Ingeniería Julio Garavito, diego.coy@mail.escuelaing.edu.co, Bogotá D.C., Colombia.

Resumen

El escenario de las energías limpias y renovables ha atravesado un proceso de transformación con el descubrimiento de nuevas fuentes de generación y dispositivos para su almacenamiento. Se buscan soluciones sostenibles y eficientes para satisfacer la creciente demanda de energía de la población actual. En todo el mundo se reconocen los problemas ambientales relacionados con los combustibles fósiles, pero, para abandonarlos y que las energías renovables puedan cubrir la demanda actual, estas no solo deben entregar la cantidad de energía suficiente, sino que además deben acumularse y transportarse. En esta perspectiva, las baterías desempeñan un papel importante en distintas áreas, desde el almacenamiento de energía, hasta la alimentación de dispositivos electrónicos, vehículos eléctricos, etc. Los dispositivos electrónicos usan relativamente poca potencia, por lo que incluso pequeñas mejoras en las baterías han impulsado grandes cambios en su desempeño y empleabilidad diaria. La funcionalidades del grafeno y del coltán los hacen idóneos para una variedad de aplicaciones, que son al mismo tiempo, oportunidades de desarrollo para Colombia, tales como: purificación y desalinización del agua, sistemas de catalización destinados a la producción de hidrógeno y de espumas para fines de alumbrado y como elemento de calentamiento rápido; el grafeno usado como material de recubrimiento fotocatalítico en edificios inteligentes puede purificar el aire de las ciudades; también es un material prometedor en los campos de la electrónica impresa, los sensores, biosensores de transistores de efecto de campo a base de grafeno (GFET), biosensores ópticos y las celdas fotovoltaicas. Actualmente se estudia la posibilidad de incorporar microchips de grafeno implantados en dientes para la detección bacteriana y la monitorización de la higiene bucal podrá facilitar el estudio y prevención de las enfermedades periodontales en el futuro; en la Universidad de Manchester se obtuvieron nuevos preservativos de grafeno gracias a los polímeros compuestos de grafeno, que brindan mayor tasa de transferencia de calor, mejorando la sensibilidad y la capacidad para dispersar, de forma uniforme, fármacos activos para prevenir enfermedades de transmisión sexual, embarazo o incluso incrementar el placer sexual. Las láminas de grafeno también han sido utilizadas recientemente para medir los niveles de glucosa en sangre a través del sudor y proporcionar dosis farmacológicas a través de la piel. Esta investigación se enfoca en un estudio de caso: el dimensionamiento de una batería de Litio con grafito en ambos electrodos como alternativa de solución para el mayor almacenamiento de energía. En este proceso se amplía la participación del grafito en ambos electrodos, específicamente en el recubrimiento del cátodo mediante capas para disminuir las pérdidas y con eso mejorar el almacenamiento de la batería. Con esta propuesta tanto el ánodo como el cátodo estarán formados por materiales intercaladores (grafito), distintos al ánodo de litio metálico que resulta peligroso, y el ion Li+1 puede viajar de manera reversible entre ellos. Como resultado del trabajo se logra diseñar en el software SolidWorks la estructura de la nueva batería que se construirá y probará en las siguientes etapas de la investigación.

Palabras clave: Grafeno, coltán, baterías, industria electrónica.

Abstract

The clean and renewable energy scenario has gone through a transformation process with the discovery of new generation sources and devices for their storage. Sustainable and efficient solutions are sought to satisfy the growing energy demand of today's population. The environmental problems related to fossil fuels are recognized throughout the world, but to abandon them and for renewable energies to cover current demand, they must not only deliver enough energy but must also be accumulated and transported. In this perspective, batteries play an important role in different areas, from energy storage to powering electronic devices, electric vehicles, etc. Electronic devices use relatively little power, so even small improvements in batteries have driven big changes in their performance and daily use. The functionalities of graphene and coltan make them ideal for a variety of applications, which are at the same time development opportunities for Colombia, such as water purification and desalination, catalyzing systems for the production of hydrogen and foams for lighting purposes, and a rapid heating element; graphene used as a photocatalytic coating material in smart buildings can purify the air in cities; It is also a promising material in the fields of printed electronics, sensors, graphene-based field-effect transistor (GFET) biosensors, optical biosensors, and photovoltaic cells. The possibility of incorporating graphene microchips implanted in teeth for bacterial detection and monitoring of oral hygiene is currently being studied, which could facilitate the study and prevention of periodontal diseases in the future; At the University of Manchester, new graphene condoms were obtained thanks to graphene composite polymers, which provide a higher heat transfer rate, improving sensitivity and the ability to disperse active drugs to prevent sexually transmitted diseases uniformly, pregnancy or even increase sexual pleasure. Graphene sheets have also recently been used to measure blood glucose levels through sweat and deliver pharmacological doses through the skin. This research focuses on a case study: the sizing of a Lithium battery with graphite in both electrodes as an alternative solution for greater energy storage. In this process, the participation of graphite in both electrodes is expanded, specifically in the coating of the cathode through layers to reduce losses and thereby improve battery storage. With this proposal, both the anode and the cathode will be made up of intercalator materials (graphite), different from the metallic lithium anode, which is dangerous, and the Li+1 ion can travel reversibly between them. As a result of the work, the structure of the new battery that will be built and tested in the following stages of the research was designed in SolidWorks software.

Key Words: Graphene, coltan, electronic industry.

1. INTRODUCTION

Currently, the electronics industry is experiencing technological advances and for its developments, it requires new materials to replace the conventional ones that are exhausted in nature; hence the need to explore new materials that meet the needs. Two minerals in particular, graphene and coltan, have emerged as protagonists in this scenario. These minerals have become key materials for developing electronic devices (photodetectors, biosensors, batteries, etc.) due to their shared physicochemical properties. On the one hand, coltan, which is a combination of columbite (changed to niobium, valence number of +3 and +5) and tantalite (valence number of +5), has become a fundamental material in the production of capacitors.

On the other hand, graphene, which is a compound of carbon atoms arranged in a hexagonal two-dimensional structure, is used in the manufacture of batteries, integrated circuits, and electronic devices in general. It is predicted that graphene batteries could reach storage levels of the order of six or nine terawatt hours (Quimica.es, 2022) by 2030. The electrical, electronic, thermal, and electrodynamic properties of both materials (superconductivity, effect of ambipolar electric field, high mobility of carriers, and ballistic transport on the submicron scale, etc.) make them attractive for new developments in the industry of digital information and communication technologies.

Currently, both graphene and coltan are essential materials for the electronics industry, being one of the main raw sources for the manufacture of electronic components such as electrolytic capacitors and components used for the manufacture of mobile phones, televisions, video game consoles, tablets, among others, as well as for the manufacture of batteries (Urcuyo *et al.*, 2020). As evident, most devices dependent on these materials are essential for most of the world's population both in work and personal life, for this reason, obtaining and developing an industry based on these minerals is of great importance and has the potential to be a great boost to economic development for Colombia, in addition to mitigating social and environmental problems that currently arise, such as illegal mining in obtaining coltan in the region (Jiménez *et al*., 2022). This article aims to improve energy storage technology through batteries in Colombia; It is proposed to implement graphite in the electrodes of a lithium battery to improve its storage capacity. The specific objectives are to present a review of the updated state of the art of coltan and graphene and to propose a first sizing of the batteries through a 3D CAD simulation using the SolidWorks tool.

2. STATE OF THE ART OF RESEARCH

The mineral compositions (niobium + tantalum) that have recently been abbreviated as coltan arose during the scientific identification of "new rare earths" in the late 18th and early 19th centuries. Niobium and tantalum are transition metals that do not appear on Earth as free elements but as components of a wide variety of oxide mineral species. In addition to columbite [(Fe, Mn) Nb2o6] and tantalite [(Fe, Mn) Ta2o6], whose are classified by the majority composition of niobium or tantalum. After their scientific-chemical discovery, columbite and tantalite rocks only ceased to be rare minerals when they began to be used industrially (TNISC 2013). In 1802, the Swede Ekeberg discovered another new "rare earth" by studying three samples from Sweden and Finland, from which he separated the mineral composition that he named "tantalite" and identified "tantalum" as its predominant element (TNISC, 2013).

Currently in Colombia, it is estimated that since 2008 coltan has begun to be exploited in 35,000 hectares between the Vichada and Guainía areas, and because the exploitation of this mineral is not yet regulated in the country, the exploitation has been carried out extralegally. Additionally, it is estimated that the profits obtained are around 40,000 to 60,000 dollars per ton, evidencing the importance of regulating and obtaining this mineral (Galvis & Fonseca, 2011).

Graphene is a flat, one-atom-thick sheet of carbon arranged in a honeycomb lattice. The carbon atoms form a sp2 hybridized network with three nearest neighbors, each at 1.42 Å. A p orbital remains unhybridized and perpendicular to the graphene plane. The finite termination of graphene results in two possible edge geometries, which are "zigzag" and "armchair", where each has its characteristic electrical properties. The "zigzag" geometries have a metallic behavior, while the structure with the "armchair" geometry presents a semiconductor behavior (Urcuyo *et al*., 2020).

Graphene has as its main properties a very high electron mobility (500 000 cm2v-1 s-1), a large surface area of 2630 m2g-1, a high Young's number of 1 TPa and a thermal conductivity of 5000 Wm-1. This mineral, deposited on the appropriate substrate, has remarkable optical properties, acquiring linear optical absorption. Its characteristic properties are thanks to its characteristic two-dimensional band gap structure (0 eV), turning graphene into a band 0 semiconductor, which allows this mineral to conduct massless charge carriers, described by the Dirac equation (Urcuyo *et al*., 2020).

Currently, various methods are used to obtain graphene from graphite oxide (solid): a) by chemical reduction, through a thermal treatment that facilitates the reduction of graphite oxide; However, this method has some drawbacks, leaving gaps in the crystal lattice that produce specific defects in the structure. This reduces the conductive capacity of graphene (Castro-Beltrán *et al.*, 2011); b) through micromechanical exfoliation, which is like the adhesive tape method studied by Geim and Novoselov; c) by oxidation of graphite, which consists of introducing oxygen groups between the graphite layers to increase the separation of the graphene layers (increase in the interplanar distance). In this way, the exfoliation process carried out with laser or ultrasound becomes much easier; d) through thermal decomposition of Silicon Carbide (SiC), which has abrasive properties, and is used to produce thin sheets of submillimeter thickness, it can be obtained by mixing sands rich in quartz with carbon coke fused in ovens at temperatures above 2,000º C. These ingredients allow the production of graphene quickly and more profitably; e) by bacterial reduction of graphite oxide. Studies carried out by Salas *et al.* (2010) demonstrate that the metabolic activity of bacteria from graphene oxide can synthesize graphene. This opens a new field of research for the extraction of this material.

Other procedures for the isolation and transformation of graphene used for gaseous or liquid phases have been proposed in recent years: gas phase, from hydrocarbons and through electrical discharges or the use of certain lasers allows the extraction of nanotubes and carbon films; liquid/solid phase, from an organic precursor such as pitches, polymers, coal or even biomass and depending on whether the material is graphitizable or not, fibers and glassy carbon (active carbons) or even graphite and diamonds can be obtained through the heat treatment in an inert atmosphere, a process called carbonization

The synthesis of graphene from carbon carried out in laboratories has already begun to give its first results, obtaining sheets and quantum dots that have applications in various fields (Zhou *et al.*, 2012; Ye *et al.*, 2013; Brownson and Banks, 2014)

Many patent applications, awards, and scientific publications highlight the multiple scientific achievements regarding the research carried out on coltan and graphene. Abundant information on these materials is found in the literature; most of them focus on the study of their properties, geological origin, extraction methods, and environmental impact.

For example, Solmeglas (2023) describes some properties of coltan: resistance to high temperatures (double that of iron), high capacity for storing electrical charges, resistance to corrosion and wear, high conductivity (greater than that of copper), is not reactive or harmful to body tissues, and is ultra-refractory. However, the potential uses of coltan and graphene are scarce, among others, the research by Vizbaras *et al.* (2022) stands out, which seeks to improve the efficiency and stability of tera-Hertz detectors, through the implementation of effect transistors. graphene-based field sensors (hereinafter GFETs); these detectors can be used in security, medical imaging, and communications applications. For the study, a semi-empirical model is proposed that uses physical parameters derived from the electrical and electrodynamic characteristics of graphene. The methodology specifies the design of the detectors, the configurations, and the effect of temperature and vacuum on the channel resistance involved, to minimize the losses that are introduced to the detector in tera-Hertz due to the thickness. of the substrate. High-impedance antennas and an oscilloscope were used in the tests. The results showed significant improvements in the efficiency and stability of the GFET detectors at room temperature, achieving a record for tera-Hertz detectors for its optical response of 80 (V/W) without normalization to the effective area of the antenna and a power 111 (pW/√Hz) noise equivalent at 336 GHz; this finding opens the doors to the world of telecommunications for graphene, as an option for efficiency and stability. In the article "Perspectives and real applications of graphene after 16 years of its discovery", Urcuyo *et al.* (2021) highlight the potential applications of graphene as the strategic and revolutionary material of this century; analyze the challenges faced by the production and use of graphene, considering factors such as cost and sustainable exploitation techniques. While Sengupta and Hussain (2022) discuss the use of graphene to improve the performance of batteries, touch screens, and transparent memories, among others; and highlight its potential in various fields, due to its high electrical conductivity and optical transmission properties. They claim that graphene could replace indium tin oxide (ITO) in the manufacture of touch screen electrodes because it improves the flexibility and durability of touch screen electrodes. Likewise, the surface area of graphene stands out for its use as a platform for the immobilization of antibodies to the SARS virus.

Sang *et al*., (2019) in their article entitled "Electronic and Thermal Properties of Graphene and Recent Advances in Graphene-Based Electronics Applications", highlight the electronic and thermal properties of graphene; they explore the applications of graphene in electronics, to verify the progress in the development of current electronic systems, and they evaluate the possibility of using this material in the implementation of solutions in biomedical engineering, human therapy and environmental protection. In the end, they conclude that graphene has unique properties, which make it a suitable material to be implemented in sensors, optical devices, and energy management systems; In addition, it can be used in tissue regeneration, cancer treatments, removal of contaminants from water, and the creation of more sustainable materials. While Splitthoff *et al*., (2020), in their work "Tantalum pentoxide nanophotonic circuits for integrated quantum technology", show that tantalum pentoxide (an element extracted from coltan) offers significant benefits in isolation for the processing of quantum states. of light in optical waveguides; in addition; describe the fabrication and characterization of integrated photonic circuit components, some examples are waveguides, ring resonators, etc., and compare elements made with tantalum pentoxide with those with silicon, to demonstrate the benefits and its application to quantum technology. The results obtained show that optical grating couplers using tantalum pentoxide improve efficiency and present low signal loss, which leads to the exploitation of Coltan's established optical properties. For their part, Seyeda & Margalit (2002) explain how the use of niobium and tantalum can improve the properties of electronic ceramics; for which, they review the properties and applications of said electronic ceramics and stop to identify the characteristics that are provided by coltan; Together, some examples of applications in the electronics industry are shown. Likewise, it explains how these elements can be used to improve mechanical resistance. As a result, it was possible to identify that these elements can improve mechanical resistance, resistance to corrosion, and electrical conductivity. The importance of these ceramics in the industries of the electronics and magnetism sector was also demonstrated, thus materializing the implementation of niobium in super-resistant alloys, in foundry industries, and when used together with tantalum, they contribute to the technological advances of electronic processors and capacitors. Ananiashvili *et al.*, (2020), in their article "Structure and Properties of Tantalum Coatings Obtained by Electron Beam Technology on Aluminum Substrates", studies tantalum coatings obtained by electron beam evaporation and the use of tantalum powder on aluminum substrates. The aim was to investigate the effect of surface treatment by argon ions and electron beams on the structure and surface properties of tantalum (an element extracted from coltan). The methodology is based on the analysis of the structure and properties of tantalum coatings through microscopy, scanning, x-ray diffraction, hardness tests, and wear resistance tests. The analysis found that the tantalum coating has a body-centered cubic crystal structure and texture. In addition, the argon ion and electron beam surface treatment improve the adhesion property, increases the density of the tantalum coating, and introduces residual stresses into the tantalum coating, which improves its wear resistance and toughness. Tantalum is also used in the production of capacitors, in the preparation of aluminum substrates by cleaning and polishing, and in the surface treatment of coatings. Finally, Ansari *et al.*, (2018) study the effect of tantalum on the dielectric and piezoelectric properties of Pb0.99(Zr0.95Ti0.05)0.98Nb0.02O3 ceramics. Ceramic samples mixed with different levels of tantalum are experimented with, and the dielectric and piezoelectric properties of said samples are measured. As a result, it is identified that the addition of tantalum in the mixture improves the dielectric and piezoelectric constant of the samples, which results in an optimization of the ceramic. Furthermore, it was observed that this improvement also affects the microstructure of the samples, decreasing the densification of the ceramics synthesized by pressure. In the end, it is concluded that the ceramics used and doped with tantalum are suitable for pulsed power devices.

Regarding initiatives in Colombia related to the use and exploitation of coltan and graphene, several technological trends and potential research areas are outlined in the Macrotrends for 2030 proposed by Colciencias (Trujillo *et al.*, 2018). The focus is on nanotechnologies and nanomaterials as primary applications of carbon-based materials, such as coltan and graphene, as well as possible uses of these materials in the electronics industry, particularly in lithium batteries. Multiple areas of potential impact are proposed, including medicine, imaging, energy and hydrogen storage, catalysis, lightweight construction, and protection against ultraviolet radiation. Medicine is emerging as the primary field for the use of nanomaterials, currently having the highest percentage of nano product use in the country. Likewise, the regulation and control of coltan exploitation in Colombia are proposed, aiming to mitigate current problems and challenges in social, economic, and environmental issues, mainly focusing on illegal mining and unregulated exploitation in indigenous territories, negatively impacting the region.

Regarding batteries, in South Australia, the famous Tesla company, led by Elon Musk, built the world's largest Lithium-Ion battery in 2017, with the capacity to store 100 MWh. With it, the efficiency of the network that had already failed to supply peak demand has been improved, causing blackouts.

3. BIBLIOGRAPHIC REVIEW

3.1 Coltan

Coltan is a mineral compound that has aroused great interest in the electronics industry; It is made up of columbite, niobium oxide with iron and manganese ($Nb2O6$), and tantalite, which in turn is a compound of tantalum oxide with iron and manganese ($Ta2O6$) (García, 2013). Their shared physicochemical properties are resistance to corrosion, very high melting temperature, superconductivity, shape memory, high coefficient of capacity, and biocompatibility (NERC 2011).

3.1.1 Main sources of obtaining.

Coltan is found mainly in central Africa and Latin America. The main coltan reserves in the world are found in the Democratic Republic of the Congo, which has 80 % of the current reserves; followed by Brazil with 10 % of the reserves, and Sierra Leone with 5 %. The other remaining 5% of the reserves are distributed in China, Australia, Thailand, Venezuela, Bolivia, and Colombia. The presence and extraction of this mineral have brought with it various social, environmental, and humanitarian problems, since, in some African and Latin American countries, there is no mining regulation for the exploitation of this mineral, so mining illegal is the protagonist (Jiménez *et al.*, 2022). However, efforts are currently being made to establish more ethical and sustainable extraction practices. In Brazil, there are already legally established companies that extract coltan, columbite, and tantalum from the subsoil (Borda & Blanco, 2020).

In Colombia, according to the data provided by the Colombian Geological Service (SGC), the potential areas for obtaining coltan are in the departments of Vichada (zones of Matraca, Danta, Venado), Guainía (Remanso Chorrobocon and in the Puinawai reserve), in Vaupés and the Catatumbo basin. Occurrences of Niobium and Tantalum (possibly 2,391,450 hectares for coltan extraction) have also been identified in the Amazon craton areas (Borda & Blanco, 2020). The extraction of columbite and tantalum in Colombia is done in an artisanal way and the open pit, with low state control, with illegal mining predominating (Borda & Blanco, 2020).

3.1.2 Current status in the industry

The properties of coltan make it a special mineral compound for the auto parts industry, the manufacture of aviation turbines, super-magnets, train tracks, nuclear reactors, gas pipelines, and automobile elements; and its physicochemical and high resistance properties are used in the manufacture of surgical steel, pacemakers and in the coating of human prostheses (Jiménez *et al.*, 2022). Coltan has led to the manufacture of cell phones, computers, radios, video games, GPS devices, automobiles (airbag activation systems), fiber optic cables, and the development of artificial satellites. Similarly, it has applications in the military sector, in the development of remote-controlled weapons; in the airline industry, with the development of navigation systems for aircraft; in the space industry, with the construction of space stations and manned spacecraft; in microelectronics, with the development of microchips; and in medicine, with the production of implants (García, 2013).

Carbons are used in the mining industry as excavator teeth and drill bits; they are also used for high-speed cutting tools and nuclear reactor coatings. Powders and chemicals are used in capacitors, high-power resistors (ceramics), light-emitting diodes (LEDs), motion detectors, touch screen technologies, batteries, and lenses with high refractive indexes for cell phones (García, 2013).

Currently, in Colombia, there are some companies dedicated to the extraction, processing, and commercialization of coltan, among which the following stand out: Coltan Mining S.A.S., which is a company specialized in the commercialization of coltan; Comercial Minerales Y Metales De Colombia S.A.S., is a simplified stock company that is dedicated to the extraction of coltan, gold, and other precious metals; Cerro Matoso S.A., is a company dedicated to the extraction and processing of nickel and other minerals, including coltan; Minercol S.A.S., is a company dedicated to the extraction and commercialization of minerals in Colombia, including coltan.

At the international level, the following are identified: METALMINRAN, which is a Venezuelan company dedicated to mining services and the commercialization of Columbite-tantalite (coltan) with minimum concentrations of 30% tantalum up to an average of 40% concentration of tantalum dioxide; Albemarle Corporation, is another American chemical company engaged in the production of a variety of chemicals, including lithium compounds used in the manufacture of lithium-ion batteries, which often contain coltan; China Molybdenum Co., Ltd., is a Chinese company specialized in the mining and processing of various minerals, including coltan; Samsung SDI, is a subsidiary of the South Korean conglomerate Samsung Group, which is dedicated to the manufacture of rechargeable batteries, including those used in electronic devices and electric vehicles, which often contain coltan.

3.1.3 Potential uses

The first record of their use dates to 1903, the year in which niobium and tantalum were used in filaments to produce lamps and incandescent bulbs, but were eventually replaced by tungsten (Bowers, 2001).

Coltan is used in the manufacture of passive electrical components: resistors and capacitors, and in the development of electronic components, because it offers notable advantages over other materials. For example, by replacing aluminum with tantalum oxide in electrolytic capacitors, higher capacitance, more compact size, and low resistance are achieved. These characteristics make it possible to protect equipment against voltage surges and guarantee reliable performance (Patiño *et al.*, 2022; Caballero *et al.*, 2022). These capacitors are manufactured with different features such as solid led, polymer, wetted, and solid SMD (Mouser Electronics, 2023).

In thin-film resistors, tantalum is used to replace nickel chrome, allowing for higher accuracy, long-term stability, and resistance to critical environmental conditions. These film circuits are found in various application sectors, from automobiles to medical equipment and communication devices (Arrow, 2016; Viking, 2022).

Coltan is also used in the production of integrated circuits, sensors, and sensing devices. In integrated circuits, tantalum capacitors store and release electrical charges, providing stability and signal filtering (Pérez, 2002). In sensors and detection devices, tantalum is used to take advantage of its physical and chemical properties, such as high electrical conductivity, resistance to corrosion, and ability to operate at high temperatures (Gutiérrez & Iturralde, 2017).

In instrumentation and control equipment manufacturing, thin-film resistors and tantalum capacitors help eliminate noise, smooth out voltage fluctuations, and provide clean, stable power, ensuring accurate measurements and precise process control. In addition, their compact size and light weight make them ideal for applications with space and weight constraints, such as mobile computers and high component density devices. Voltage regulators can also use integrated circuits, capacitors, or resistors that contain tantalum (Gutiérrez & Iturralde, 2017). In the field of manufacturing alarms, coltan is used in voltage regulation systems, sensors, panels, and other control and instrumentation devices (Orozco, 2017).

Batteries also benefit from the use of coltan; in particular, tantalum is used in the improvement of lithium-ion batteries, by adding layers of tantalum nanoparticles together with silicon. This results in batteries with higher capacity, more stable protective layers, and greater support for charge and discharge cycles (NCYT Amazings, 2021; Ruiz *et al.*, 2022). In the field of consumer electronics, coltan finds applications in tantalum capacitors and film resistors. These components are widely used in mobile phones, tablets, and other consumer electronics, as they allow for miniaturization, offer charge storage capacity, and provide long-term stability (Gasex Academy, 2022). In renewable energy generation, although coltan is not used in transducer elements, it can find applications in additional circuits, such as storage batteries, as well as in control devices and sensors used in this area. In addition, the optical properties of coltan synthesized at high temperatures make it suitable for solar receptors (Carvajal, 2020). Finally, coltan finds applications in aerospace and military technology. In alloys with specific metals, Tantalum forms superalloys, which are capable of withstanding extreme temperatures and stresses. These are used in commercial and military aircraft turbine engines, allowing for higher internal combustion temperatures and greater thrust (Industry Surfer, 2022)

3.2 Graphene

It is a two-dimensional material composed of a layer of carbon atoms arranged in a hexagonal structure; It has been the subject of numerous investigations due to the great interest it has aroused in the scientific and technological community. Some studies have explored the properties of graphene; others have focused on synthesis methods, potential applications, and associated challenges. According to ATRIA Innovation (2020), some properties of graphene are high thermal conductivity, high electrical conductivity, high elasticity and flexibility, high resistance, and high density (it does not allow Helium atoms to pass through, but it does allow water to pass through, which evaporates at the same speed as if it were in an open container). In addition, it is a transparent, lightweight material (100,000 thinner than a hair, and a square meter of graphene weighs less than a gram; that is, it weighs 200 times less than steel), has high hardness (the Graphene is approximately 200 times more resistant than steel, similar to the resistance of diamond, but much lighter), it is not affected by ionizing radiation and is repellent to water and corrosion (it is water-repellent). Graphene can generate electricity by exposure to light and is a frequency multiplier. It is characterized by its antibacterial effect (bacteria are not able to grow in it), low Joule effect (heating by conducting electrons), and low electricity consumption compared to other compounds (graphene is better than silicon). This material is two-dimensional (each layer is one atom thick), and hybrid, so it cannot be considered a conductor, semiconductor, or insulator (it shares characteristics of conductors and semiconductors); it is a self-healing material (if a layer of graphene loses some carbon atoms for any reason, the atoms near the hole can interact with neighboring atoms and reduce the size of the hole); this ability can increase the longevity of materials made from graphene.

The properties make graphene an unusual material since it is located at an intermediate point between metals and semiconductors. This is evidenced in Figure 1, which shows the composition of the conduction and valence bands, and the separation between them by the Fermi level. The valence and conduction bands of graphene have a conical and inverted conical shape respectively; The Fermi level is located at the common point of union of both bands.

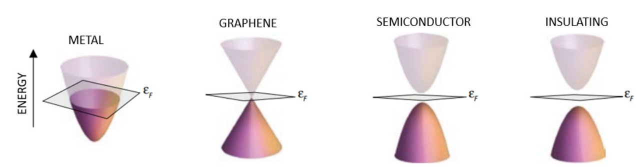

Figure 1. Conduction and valence bands of graphene concerning the group of metals, semiconductors, and insulators.
Source (Rodríguez & Kharissova, 2008).

3.2.1 Main sources of obtaining.

The source countries of raw material to obtain graphene, considering that this material is obtained from coal, are China (32 % of the reserves), followed by Poland (19 %), Russia (7.3 %), Mozambique (7.3 %), Colombia (6 %), United States (3.8 %), Australia (2.6 %); and with percentages less than 1% are: Chile, Argentina, and Venezuela, (National Mining Agency, NF). Figure 2 shows the distribution of coal mining worldwide.

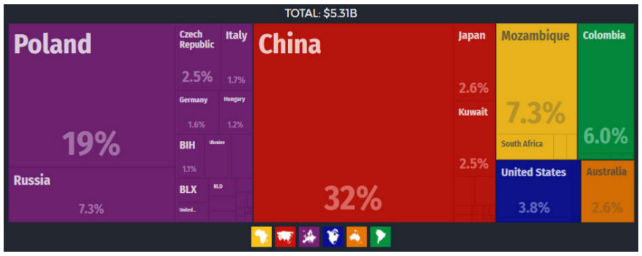

Figure 2. Distribution of coal reserves in the world Source: (National Mining Agency, NF).

Graphene is obtained by synthesis. Some methods used are micromechanical exfoliation, chemical exfoliation, graphite oxide exfoliation by thermal expansion, and ultrasonic dispersion (Ortega *et al.*, 2017). Micromechanical exfoliation consists of the separation of the outermost layer of a solid into sheets, where the surface of graphite, which must be clean, new, and smooth, is subjected to a fine and uniform scraping by using any surface object. solid. Chemical exfoliation consists of interspersing atoms into the graphite mass so that the graphene planes can be separated into layers attached to the inserted atoms (Rodríguez & Kharissova, 2008). An investigation carried out at the University of Manchester (González *et al.*, 2010), shows the obtaining of graphene sheets and the characterization of different thicknesses; it was also shown that the number of current carriers, electrons, or holes in graphene could be adjusted using electrodes.

3.2.2 Current status in the industry

In Colombia there are several companies dedicated to the extraction, processing, and commercialization of graphene; among others, Graphene Investments S.A.S: is a private technology-based company dedicated to the production of high-quality graphene-based engineering nanomaterials; Orbis Group: is another company that works on the development and application of advanced materials, including graphene, in the construction, energy and automotive sectors. Changing the scenario, in the international context, industries that use graphene for the development of new technologies are identified; Some examples are: NanoInnova Technologies, which focuses on the development and commercialization of graphene-based products and applications, such as sensors, batteries, and coatings; Graphenea, is a company that offers a wide range of graphene products and works in collaboration with different industries to develop innovative applications; Haydale Graphene Industries, is another company that focuses on the production and treatment of graphene and other nanomaterials; work in collaboration with different sectors, such as automotive, aerospace and energy, to develop new products.

3.2.3 Potential uses

The monolayer characteristic of graphene and its ability to transmit electrons through potential barriers through tunneling benefit the construction of carbon transistors. Similarly, its properties that favor the quantum Hall effect and ballistic transport contribute to the manufacture of ballistic transistors (Rodríguez & Kharissova, 2008). Another possible application of graphene is the construction of spin valve devices, due to the irrelevance of the orbit–spin coupling, so that the spin polarization subsists at sub-micrometer distances (Rodríguez & Kharissova, 2008). The bilayer characteristic of graphene, useful for the absorption of gas molecules in the atmosphere, is used to control atmospheric pollution through its application in solid-state gas sensors (Rodríguez & Kharissova, 2008).

In the electronics sector, graphene is used to produce low-cost electrically conductive materials; for this, it mixes graphene powder obtained from micrometric crystals not coagulated with plastic. Graphene is also used to produce electric batteries, taking advantage of the high conductivity and surface-to-volume ratio of graphene powder; When comparing these batteries with lithium ones, better efficiency is achieved, surpassing current lithium batteries by more than 210 times the storage capacity. In printed circuits, graphene is used to produce conductive inks; in computing for the manufacture of hard drives with greater capacity; in the mobile phone industry, to produce folding and flexible screens for smartphones; and in transmission media, for the construction of photodetectors, taking advantage of the superior capacities of graphene over silica, in capturing light (Rodríguez & Kharissova, 2008).

Similarly, the characteristics and properties of graphene position it as a good candidate for applications in future technologies. There are many expectations in quantum computing, as it is an ideal material to produce spin qubits, and in hydrogen storage, thanks to its ability to absorb this type of gas. In the same way, with the advances made in the synthesis of graphene oxide sheets, possibilities are opened for its use in membranes with controlled permeability in anisotropic ionic conductors, in superconductors, and in materials for molecular storage (Rodríguez & Kharissova, 2008).

3.3 Specific opportunities and challenges related to the electronics industry in Colombia.

The Colombian electronics sector holds a range of possibilities and challenges that are of utmost importance for its development and sustained growth. Firstly, the country boasts valuable natural resources, including coltan, an essential mineral in the manufacturing of electronic devices, providing it with a competitive advantage in the production of electronic products both domestically and internationally. Furthermore, Colombia has demonstrated its capacity to research graphene, an example of which can be seen in the article published by the University of Antioquia titled "*A laser made with the 'God material*'" (Restrepo De La Pava, J., 2019). This is a material with exceptional electronic properties that promises to transform the industry.

However, significant obstacles that require attention are also present. Colombia's technological infrastructure still requires substantial improvements to meet the growing demand of an expanding electronic industry. Additionally, international competition is rigorous, as Colombia must compete with countries that have established a strong position in the production of electronic devices. To succeed in the industry, it is crucial to cultivate a highly skilled workforce in disciplines such as electronic engineering and nanotechnology, which entails investing in high-quality educational programs and technical training.

To capitalize on these opportunities and overcome the challenges, it is suggested to implement key strategic actions. This includes injecting resources into research and development, promoting excellence in educational programs, adopting robust environmental policies and effective regulations to ensure sustainability, supporting the export of Colombian-manufactured electronic products, and fostering collaboration between the government, the private sector, and academic institutions. The private initiative needs to commit to this, participating in research projects and studies, supported by public capital. With a well-coordinated strategic focus, Colombia can advance its position within the electronics industry and fully harness its economic and technological potential.

3.4 Batteries

One of the largest applications of graphene is in the manufacture of batteries (Dong *et al.*, 2012). Graphene templates allow the creation of metal oxide structures that improve electrodes and catalysis. A small film of folded zinc oxide becomes up to 4 times more reactive as it has a larger surface area, providing the material with more reactive points.

3.4.1 General principle of operation of any traditional battery (voltaic or galvanic)

The operating principle is the same: an anode and a cathode, separated by an electrolyte, undergo oxidation-reduction reactions that deliver and receive electrons in a circuit: the anode oxidizes and delivers electrons to the circuit, and the cathode reduces by taking electrons from the circuit. Electrons travel from the anode to the cathode passing from a high-energy state to a low-energy state. Consequently, the battery voltage is physically determined by the difference in potential energy that the electrons have when they are associated with the anode (high) and the one they have when they are associated with the cathode (low). When the anode material finishes oxidizing, or the cathode finishes reducing, the battery has already delivered all the energy it had stored.

3.4.2 Lithium-ion battery

This battery (Figure 3) uses graphite in the anode, which houses lithium atoms in an intercalated manner. Surrounded by graphite, lithium is protected from reacting with air or water virtually indefinitely. This battery is widely used due to its high energy density, long life, and low self-discharge levels. Figure 3 shows the external and internal parts of an 18650 Lithium-Ion battery.

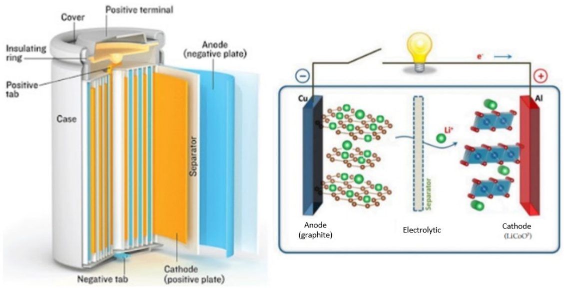

Figure 3. Parts that make up the Ion-Lithium battery.
Source: (González, 2013).

The main components are the anode, which is usually made of graphite; the cathode, which is a lithium alloy (LiFPO4, LiCoO2, LiMn2O4, etc.); the electrolyte which is a lithium salt in an organic solvent (polymer); and a separator that is generally a porous polymer. In addition to the packaging, the terminals, insulators, and other security elements. The cells used can be cylindrical or prismatic; in both cases, it is a rolled sandwich of the anode, cathode, and separator, to which the electrolyte is then added. During charging, lithium moves from the cathode to the anode. When downloading, it does so in the opposite direction. These processes are accompanied by oxidation and reduction chemical reactions with their corresponding electron balances.

During the charge and discharge processes, lithium leaves the cathode structure and accumulates in the anode, forming a graphite intercalation compound; LiC6, LiC12, or LiC18. The formation of the intercalation compound is a reversible process, which can occur in the opposite direction and release lithium. But unwanted reactions can also occur, in which lithium accumulates in the anode in the form of lithium oxide and therefore there is less lithium available in the battery, capacity is lost. The formation of lithium oxide is an irreversible process, there is no going back.

3.4.3 Proposal of work

It is about expanding the participation of graphite in both electrodes, specifically in the cathode coating using layers to reduce losses and thereby improve battery storage.

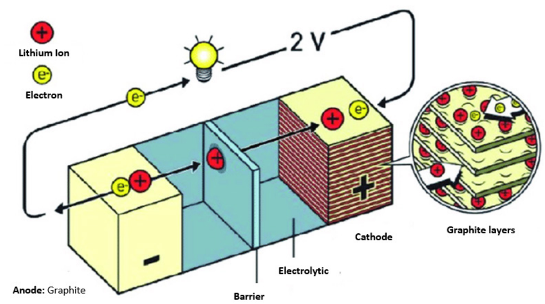

Figure 4. New composition of the Ion-Lithium battery.
Source: Authors

4. METHOD AND MATERIALS

Battery manufacturing varies by technology; to explain the process, the Lithium-Ion battery will be taken as reference, which is popular and commonly used in electronic devices (Cohen, 2021).

According to ETN (2021), three stages are identified in the manufacture of this type of battery: stage 1 is the manufacture of electrodes that begins with the mixture of the materials of the electrodes with a conductive binder to form a uniform suspension (the material an anode is a form of carbon and the cathode is an oxide of lithium metal); continuous with the suspension consisting of continuous or intermittent coating on both sides of the current collector; aluminum foil is used for the cathode (this negatively charged electrode undergoes a reduction reaction, whereby a material reduces its oxidation state by receiving electrons), and for the anode (an oxidation reaction occurs at this electrode, by which a material loses electrons, increases its state of excitation) copper foil is used. An application tool (like a groove), doctor blade, or anilox roll is used for suspension; the thickness is controlled by the coating machine. The coated sheet is introduced directly into a drying oven to evaporate the solvent. The calendaring process continues in which the sheets are compressed by a pair of rotating rollers; this helps adjust the physical properties (junction, conductivity, density, etc.) of the electrodes. The finished electrodes are cleaned and fed into cutting machines to turn them into narrow, rolled strips; they are then sent to a vacuum oven to remove moisture and residual solvent. Stage two is the assembly of the cells, which begins with the separation of the electrodes; then they are sent to the controlled environment room for sub-assembly; here, the separator is placed between the anode and the cathode to form the internal structure of the cell; In that process, two basic electrode structures are used depending on the type of cell housing (stacked for bag-type cells and rolled for cylindrical and prismatic cells). The cell structure is connected to the cell terminals, along with a safety device, by laser or ultrasonic welding. The sub-assembly is then inserted into the cell housing, to be sealed by welding or heating, ensuring an opening to inject the electrolyte. Subsequently, the housed cell is filled with electrolyte (it is the ionic conductor that provides the medium for charge transfer in the cell) using a high-precision dispensing needle and sealed. The last stage is the completion of the cell: it begins with the first charges and discharges of the battery cell; cells are then placed on forming racks and connected by spring-loaded contact pins; and then the cells are charged or discharged according to the defined current and voltage curves. This causes lithium ions to embed themselves in the crystalline structure of the graphite on the anode side, forming a protective layer called the solid electrolyte-electrolyte-electrode interface. In large bag-type cells, the first charge causes a strong gas evolution, this can be expelled from the cell towards a dead space; during degassing, the gas bag is pierced in a vacuum chamber and sucked out; at the end, the cell is sealed under vacuum. This step is called aging and is carried out for quality purposes. During this process, the characteristics and performance of the cell are monitored by regular measurement of the open circuit voltage over a period of three weeks. Generally, tests are done at high temperatures, and later, at room or normal temperature. If there is no significant change in the properties of the cell, it is considered functional; they are then tested on an end-of-line platform. The cells are discharged to the shipping state of charge to measure their capacity, at the test station. Additional pulse, leakage, internal resistance, etc. tests are also done. Once the tests have been completed, the cells are assembled in packages for commercialization. It is worth mentioning that the active materials, conductive additives, solvents, and binders, as well as the aluminum foil and copper foil, are usually components purchased by the cell manufacturer.

Knowing the background of battery manufacturing, the opportunity arises to explore production alternatives with new materials. In this perspective, graphene and coltan are considered as possible substitutes for lithium, to take advantage of their properties. This option replaces the use of elements such as cobalt, and nickel, and minimizes the use of metallic elements (aluminum, steel, copper) in manufacturing; for example, the use of metal in battery terminals (Hybrids and Electrics, 2023). Thus, more sustainable batteries and less harmful to the environment would be produced.

The manufacture of batteries with graphene or coltan will initially be more expensive, compared to the current production of conventional batteries, due to the complexity of the technologies for obtaining and processing both materials; although, there is the possibility of making alloys with other cheaper materials, such as polymers.

For the manufacture of batteries with new materials, the following is proposed: 1) Preparation of materials: the necessary ones are selected, including graphene, which will be implemented in the electrodes, both in anode and cathode. For this, graphene can be produced by chemical vapor deposition methods or the most convenient method; 2) Coating of the electrode: with the graphene already prepared, a layer is applied in the same locations of the electrodes (replacing the copper and aluminum sheets). This can be achieved with coating techniques, such as sputtering or atomic layer deposition. 3) Cell assembly: the anode and cathode layers are stacked with the separator in the middle, to avoid direct contact between them. This process can vary depending on the type of battery, whether bag or cylindrical, among others. 4) Electrolyte injection: The electrolyte is introduced into the cell using a dosing needle and then it is sealed. 5) Activation, for this phase, the battery is repeatedly charged and discharged to activate the graphene and stabilize the battery capacity; Current curves are drawn from the responses. 6) Aging: the battery will undergo different tests, for a couple of weeks, in which the performance of the energy storage device, safety, and quality will be evaluated.

5. RESULTS

Next, the 3D design of the lithium battery with graphene implemented in its electrodes is presented. It was simulated in SolidWork®.

Two shapes were considered: cylindrical and rectangular (see Figure 5), taking as reference a 3.7 V Lithium-Ion battery at 2200 A/h, which can have from 1 to 6 cells.

Figure 5. Commercial forms of Lithium-Ion batteries.
Source: Authors

The dimensions were: 1) the cylindrical battery, made up of a shell (outer diameter:

18mm, total height: 60mm), compartments: lithium cell (inner diameter: 16 mm, height: 50mm), of graphene anode and cathode (inner diameter: 16mm, height: 2mm), and for the protection circuit (inner diameter: 16mm, height: 4mm). 2) For rectangular battery, made up of housing (50mm, width: 32mm and depth: 10mm), lithium cell compartments (height: 44mm, width: 30mm and depth: 8mm), of the graphene anode, cathode, and protection circuit (height: 4 mm, width: 30mm and depth: 8mm). The results of the 3D simulation for the rectangular battery are shown in Figures 6 to 9.

In the sizing of the rectangular battery, the following measurements were considered: 48 mm in height, 30 mm in width, and 8 mm in depth; with these dimensions a volume of 0.00001152 mm^3 is occupied (figure 6).

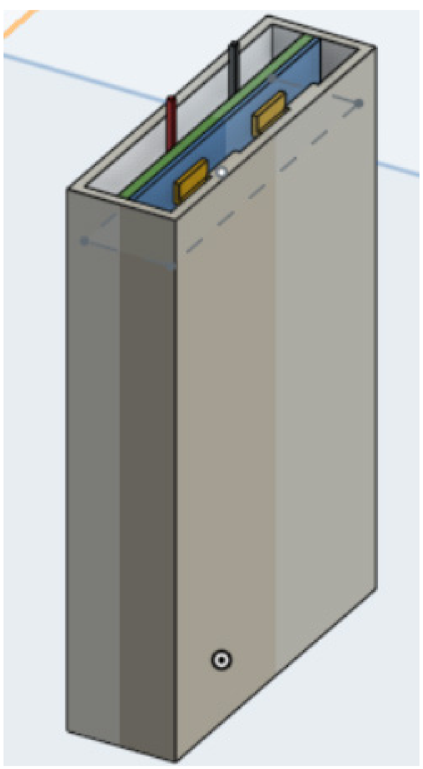

Figura 6. External battery configuration. Source: Authors

44 mm height was assigned for the cells as shown in figure 7.

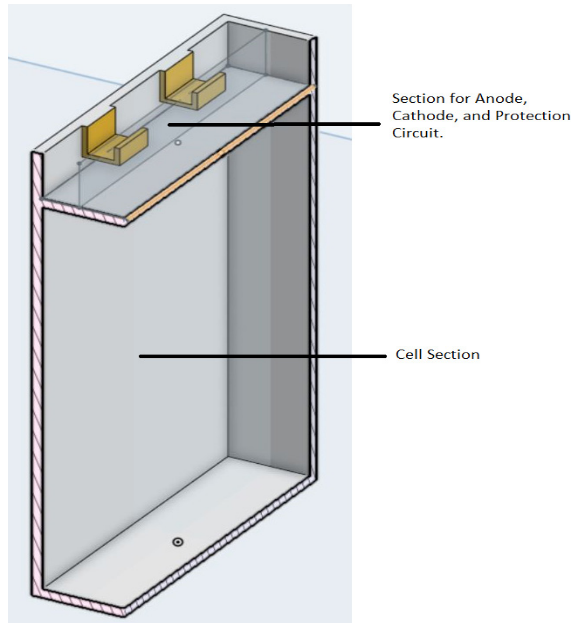

Figure 7. Internal battery configuration. Source: Authors

The remaining 4 mm to complete the total height was used for the electrodes and the protection circuits (figure 8).

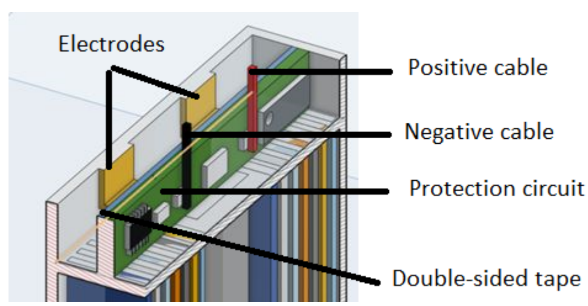

Figure 8. Top compartment design. Source: Authors

Figure 9 shows both compartments with their constituent elements.

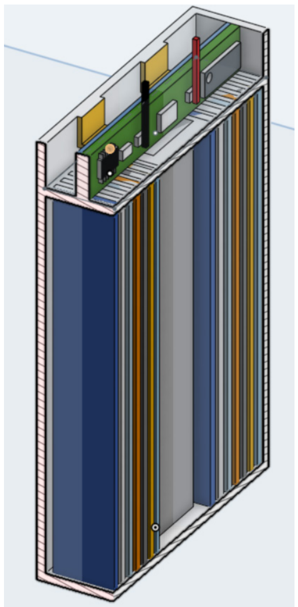

Figure 9. Battery total internal schematic. Source: Authors

Figures 10 to 12 show the cylindrical lithium-ion battery. Figures 10 and 11 show the constituent parts of the battery.

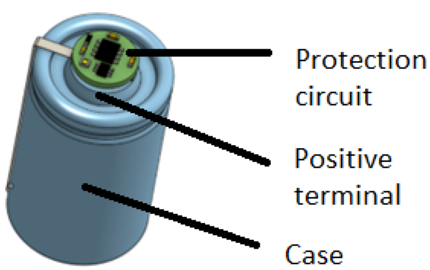

Figure 10. Battery profile view. Source: Authors

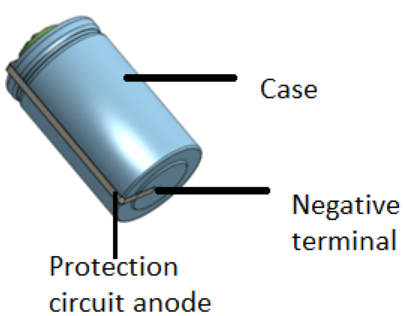

Figure 11. Cylindrical battery schematic. Source: Authors

Figure 12 shows the internal structure of the battery, in which a compartment of 16 mm in diameter and 48 mm in height can be distinguished, to locate the cells that are rolled up. On the back of the battery a compartment of 16 mm in diameter and 2 mm in height is assigned to locate the electrodes and protection circuits.

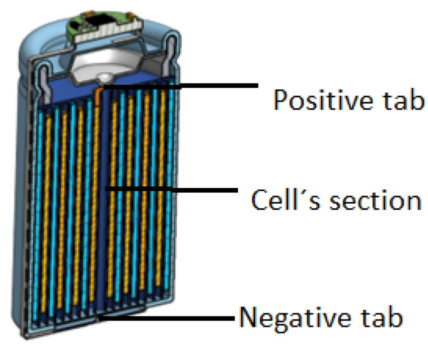

Figure 12. Internal schematic of the battery. Source: Authors

6. ANALYSIS OF RESULTS

The presence of the underlying substrate in the battery limits the applicability of graphene in electronics, the reason being that the intimate coupling between metal and graphene alters the electronic properties of graphene (Urcuyo *et al.*, 2021).

Li-Ion batteries with graphite electrodes improve conductivity and reduce losses due to the internal resistance of the cell. This resistance is 2 to 6 milliohms and increases with the age of the battery, decreasing its discharge rate.

The structure and chemical functionality of graphene and coltan give possibilities to control the electronic properties, which could be used in chemical sensors or molecular electronics. Additionally, it presents applications in areas such as water treatment, solar cell energy collectors and photodetectors, energy storage (different battery configurations), and biosensors of different ranges. It is important to standardize procedures that allow synthesizing these materials at an industrial level. It has been shown that graphene still presents reproducibility problems in different devices (Urcuyo *et al.*, 2021).

7. CONCLUSIONS

Fortunately, and although it is not obvious, the composition of the cathode has not stopped improving in recent years, always looking for better performance, lower losses, and greater durability. The use of graphite layers in the cathode composition could be the solution to the difficulties encountered in this incessant search for material variations and proportions of new compounds.

A lithium battery can store 0.2-0.6 kWh of energy per liter. So, gasoline, with 9 kWh/l is still an order of magnitude more compact than today's best batteries.

At the end of the useful life of the batteries, waste must be properly managed and, in some cases, lithium and graphene can be recycled. Recycling is an important part of sustainability and can be an opportunity to close the loop of the value chain.

REFERENCES

Academia Gasex. (2022). *Tu teléfono celular tiene tantalio, ¿sabes qué es?.* GASEX. https://gasex.cl/noticias/tu-telefono-celular-tiene-tantalio-sabes-que-es/#:~:text=El%20tantalio%20se%20usa%20para,-consolas%20de%20video%2C%20por%20ejemplo

Arrow. (2016, 7 de diciembre). *Las ventajas y desventajas de los capacitores de tantalio.* Recuperado de: https://www.arrow.com/es-mx/research-and-events/articles/the-ups-and-downs-of-tantalum-capacitors

ATRIA Innovation. (2020). *¿Qué es el grafeno? Características y aplicaciones del grafeno.* https://www.atriainnovation.com/grafeno-caracteristicas-aplicaciones/#:~:text=Aplicaciones%20del%20grafeno,-Debido%20a%20las&text=En%20el%20campo%20de%20la,por%20ejemplo%20la%20energía%20solar.

Borda, G. D., & Blanco, M. Y. (2020). *Análisis del* *proceso minero del coltán y sus implicaciones ambientales y jurídicas en Colombia.* Universidad Distrital Francisco José de Caldas.

Bowers, B. (2001). Scanning our past from London. The filament lamp and new materials. Proceedings of the IEEE 89(3): 413-415

Brownson, D. A., & Banks, C. E. (2014). The handbook of graphene electrochemistry. London: Springer.

Caballero, J. A., López, R. D., Jasso, H., Reyes, M. M., & Maldonado, A. (2022). *Evaluación de la fuga de corriente en capacitores electrolíticos mediante dos procesos de envejecido.* Ciencia Latina. Vol. 6, n.º 4, p. 3516-3530. DOI: https://doi.org/10.37811/cl_rcm.v6i4.2857

Carvajal, M.C. Y. (2020). *Síntesis y caracterización de TaC usando diferentes fuentes de calor y evaluación de sus propiedades ópticas.* Universidad Autónoma de Sinaloa, Facultad de Ingeniería Mochis.

Castro-Beltrán, A., Sepúlveda Guzmán, S., De la Cruz Hernández, W. J., & Cruz Silva, R. (2011). Obtención de grafeno mediante la reducción química del óxido de grafito. Ingenierías, 14(52), 34-42.

Cohen, A. (2021, February 11). What batteries will power the future? Forbes. https://www.forbes.com/sites/arielcohen/2021/02/11/what-batteries-will-power-the-future/?sh=5ba99e3341c0

Colombia. Agencia Nacional de Minería. (NF). *Carbón.* https://www.anm.gov.co/sites/default/files/DocumentosAnm/carbon.pdf

Dong, X., Wang, J., Wang, J., Chan-Park, M. B., Li, X., Wang, L., Huang, W., & Chen, P. (2012). Supercapacitor electrode based on three-dimensional graphene–polyaniline hybrid. Materials Chemistry and Physics, 134(2), 576-580.

ETN News. (2021, June). Li-ion Cell Manufacturing. https://etn.news/energy-storage/li-ion-cell-manufacturing

Forococheselectricos. (2021). La revolución de las baterías llegará con un pack fabricado con una mezcla de grafeno y polímeros. Forococheselectricos. https://forococheselectricos.com/2021/07/revolucion-de-las-baterias-pack-fabricado-con-una-mezcla-de-grafeno-y-polimeros.html

Galvis Santacruz, L. C., & Fonseca, R. A. (2011). *El Coltán En Colombia, Entre Ganancias Globales Y Problemáticas Locales - Dinámicas Hacia Una Nueva Vorágine*. Revista Clepsidra. Vol. 7, n.° 12, p. 33-42. DOI: https://doi.org/10.26564/19001355.61

García, I. A. (2013). *Coltán, el Oro Negro del Siglo XXI.* Universidad de Palermo.

González, J., Vozmediano, M. A. H., & Guinea, F. (2010). *Electrónica del grafeno.* Investigación y Ciencia. Vol. 408, p. 42–49. URI: http://hdl.handle.net/10261/32750

González, L. (2013). <<forococheselectricos.com>> Vida y muerte de una batería de ion litio (parte II). En línea, disponibles https://forococheselectricos.com/2013/05/vida-y-muerte-de-una-bateria-de-ion-2.html, Consultado 07/15/2023.

Gutiérrez, M., & Iturralde, S. (2017). *Fundamentos básicos de instrumentación y control.* (1ra ed.). Ecuador: Universidad Estatal Penínsulala de Santa Elena.

Híbridos y Eléctricos. (2023, 30 de enero). Baterías de grafeno y sin metales: el proyecto español que quiere revolucionar el coche eléctrico. https://www.hibridosyelectricos.com/coches/baterias-grafeno-proyecto-espanol-revolucionar-coche-electrico_67716_102.html

Industry Surfer. (2022). *Aplicaciones principales del tantalio.* Industry Surfer. https://industrysurfer.com/blog-industrial/aplicaciones-principales-del-tantalio/

Jiménez, P. E., Merchán, L. A., Pita, D., & Muñoz, D. (2022). *Explotación de coltán en Colombia, una nueva fuente de financiación ilícita.* Cartografía de la explotación ilícita de recursos naturales en Colombia, Escuela Militar de Cadetes General José María Córdova, p. 89–118. DOI: https://doi.org/10.21830/9786289514667.03

Mouser Electronics. (2023). *Capacitores de tantalio.* https://co.mouser.com/c/passive-components/capacitors/tantalum-capacitors/

NCYT Amazings. (2021). *Hacia una mejora sustancial de las baterías de iones de litio.* https://noticiasdelaciencia.com/art/41083/hacia-una-mejora-sustancial-de-las-baterias-de-iones-de-litio

NERC (Natural Environment Research Council). (2011). Niobium-tantalum. London: British Geological Survey

Orozco, C. A. (2017). *Tecnologías de integración en la seguridad electrónica destinadas al servicio de monitoreo de alarmas para los hogares en Cali Valle.* Universidad Militar Nueva Granada. URI: http://hdl.handle.net/10654/15890

Ortega, F., Martín, S., & Carlos, H. (2017). *El Grafeno y la Minería en América Latina: Escenario al 2030.* Uam.mx. https://www.uam.mx/altec2017/pdfs/ALTEC_2017_paper_448.pdf

Patiño, J. L., Contreras, E. L., & Posada, R. (2022). *Optimización de materia prima en la industria de capacitores.* Ciencia Latina. Vol. 6, n.º 5, p. 2249-2259. DOI: https://doi.org/10.37811/cl_rcm.v6i5.3247

Pérez, A. (2002). *De la tecnología de fabricación de transistores y circuitos integrados.* Vol. 5, n.º 39, p. 1–30. DOI: https://doi.org/10.15178/va.2002.39.1-30

Química.es. (2023, 7 julio). Estudio del mercado de las baterías: la eficiencia y la sostenibilidad son las tendencias más importantes. https://www.quimica.es/noticias/1178381/estudio-del-mercado-de-las-baterias-la-eficiencia-y-la-sostenibilidad-son-las-tendencias-mas-importantes.html

Rodríguez, C., & Kharissova, O. V. (2008). *Propiedades y aplicaciones del grafeno.* Ingenierías. Vol. 11, n.° 38, p. 17–23. URI: http://eprints.uanl.mx/id/eprint/10375

Ruiz, J. C., del Río, D. S., Martínez, M. V., & Lázaro, M. J. (2022). *Catalizadores basados en tantalio y nanofibras de carbono para electrodos bifuncionales de oxígeno.* XV Reunión del Grupo Español del Carbón, Actas. p. 263-264. URI: http://hdl.handle.net/10261/270561

Salas, E. C., Sun, Z., Lüttge, A., & Tour, J. M. (2010). Reduction of graphene oxide via bacterial respiration. AcS Nano, 4(8), 4852-4856.

SOLMEGLAS. (2023, 21 de mayo). *¿Qué es el coltán? Posibilidades de este material.* https://solmeglas.com/que-es-el-coltan-aplicaciones/#:~:text=Podemos%20encontrar%20coltán%20en%20móviles,de%20resistencias%20de%20alta%20potencia

TNISC (Tantalum-Niobium International Study Center T.I.C.). (2013). Documento aclaratorio sobre las fuentes del 'coltan'. Lasne: Tantalum-Niobium International Study Center (T.I.C.). http://tanb.org/coltan

Trujillo, I. M., *et al.* (2018). *Macrotendencias hacia el 2030, El mundo y América Latina*. Colciencias – Subdirección General – Unidad de Diseño y Evaluación de Políticas. N.° 2. https://minciencias.gov.co/sites/default/files/documentos_de_trabajo_macro_tendencias_2030_nov_2018_1.pdf

Urcuyo, R., Gonzáles-Flores, D., & Cordero-Solano, K. (2020). *Perspectivas y aplicaciones reales del grafeno después de 16 años de su descubrimiento*. Revista Colombiana de Química. Vol. 50, n.º 1, p. 51-85. DOI: https://doi.org/10.15446/rev.colomb.quim.v50n1.90134

Viking. (2022). *Resistencia de chip de precisión de película delgada de nitruro de tantalio (Serie TAR).* https://www.viking.com.tw/es/category/Resistencia-de-chip-de-precisin-de-pelcula-delgada-de-nitruro-de-tantalio-serie-TAR/Resistor-Thin-Film-Resistor-TAR.html

Ye, R., Xiang, C., Lin, J., Peng, Z., Huang, K., Yan, Z., Cook, N.P., Samuel, L.G., Hwang, Ch.Ch., Ruan, G., Ceriotti, G., Raji, A.O., Martí, A., & Ceriotti, G. (2013). Coal as an abundant source of graphene quantum dots. Nature communications, 4.

Zhou, Q., Zhao, Z., Zhang, Y., Meng, B., Zhou, A., & Qiu, J. (2012). Graphene sheets from graphitized anthracite coal: preparation, decoration, and application. Energy & Fuels, 26(8), 5186-5192.