Journal of
Composites Science

MDPI

Review

Recent Development of Graphene-Based Composites for Electronics, Energy Storage, and Biomedical Applications: A Review

Felipe J. Elizalde-Herrera [1], Pablo A. Flores-Soto [1], Luis F. Mora-Cortes [1,2], Francisco J. González [1], Gustavo Soria-Arguello [2], Felipe Avalos-Belmontes [1], Rosa I. Narro-Céspedes [1,*] and Mario Hoyos [3,*]

1 Faculty of Chemical Sciences, Autonomous University of Coahuila, Saltillo 25280, Mexico; f.elizalde@uadec.edu.mx (F.J.E.-H.); alexis.soto@uadec.edu.mx (P.A.F.-S.); l.mora@uadec.edu.mx (L.F.M.-C.); fgonzalezgonzalez@uadec.edu.mx (F.J.G.); favalos@uadec.edu.mx (F.A.-B.)
2 Department of Macromolecular Chemistry and Nanomaterials, Center for Research in Applied Chemistry, Saltillo 25294, Mexico; gustavo.soria@ciqa.edu.mx
3 Instituto de Ciencia y Tecnología de Polímeros, ICTP-CSIC, Juan de la Cierva, 3, 28006 Madrid, Spain
* Correspondence: rinarro@uadec.edu.mx (R.I.N.-C.); hoyos@ictp.csic.es (M.H.)

Abstract: Nanomaterials are attractive materials for researchers because they have essential characteristics in terms of their properties. Carbon has an ample range of crystalline allotropes. Some, such as graphite and diamond, have been known since ancient times, while new forms of carbon with potential for various applications have been discovered in recent decades. Since the discovery of graphene 20 years ago, research has increased on composite materials that take advantage of carbon structures for their electrical, thermal, and mechanical properties and their ability to be synthesized at the nanometer scale. Graphene has stood out above other nanomaterials due to its surprising properties and high impact on technological research, so its uses have diversified in different areas of science such as medicine, electronics, engineering, etc. This work aims to show some new and innovative applications of graphene, on which we can see its versatility as engineering material. It also seeks to show its potential in research and development processes for its use. These are key components of advanced graphene-based materials systems under active development, with an eye on the future of advanced materials science and technology.

Keywords: graphene; allotropes; energy storage; medical applications; composites; electronics; sensors

check for updates

Citation: Elizalde-Herrera, F.J.; Flores-Soto, P.A.; Mora-Cortes, L.F.; González, F.J.; Soria-Arguello, G.; Avalos-Belmontes, F.; Narro-Céspedes, R.I.; Hoyos, M. Recent Development of Graphene-Based Composites for Electronics, Energy Storage, and Biomedical Applications: A Review. *J. Compos. Sci.* **2024**, *8*, 481. https://doi.org/10.3390/jcs8110481

Academic Editor: Hu Liu

Received: 1 October 2024
Revised: 30 October 2024
Accepted: 8 November 2024
Published: 19 November 2024

1. Introduction

Due to their unique structures, carbon materials have emerged as potential candidates in various fields of materials science [1]. Carbon allotropes have been the focus of attention of the scientific community during the last decades, especially nanosized structures like carbon nanotubes or graphene, where the latter has garnered remarkable attention since its isolation in 2004 [2]. Graphene presents a carbon monolayer with a hexagonal 2D structure and possesses exceptional mechanical, thermal, and electrical properties. Moreover, graphene presents significant potential for enhancing composite materials across various applications [3,4].

Since the discovery of graphene by Novoselov et al., a very prosperous area of research with continuous novel advances for multiple applications has come to light. They found a way to mechanically exfoliate graphite to obtain two-dimensional sheets of a material, which they named graphene, for which they won the Novel Prize in Physics in 2010. Figure 1 presents the structure of carbon nanostructures of different dimensions, such as fullerenes with 0D, carbon nanotubes with 1D, or graphite with 3D. Graphene-based materials include single-layer graphene, laser-induced graphene, carbon nanotubes, graphene oxide, and reduced graphene oxide [5]. Its properties make it a very versatile material for the benefit of humanity, which has led to very diverse and potential applications. Thus, it can be said that this discovery has revolutionized materials science, which some consider to be the cornucopia of new physics [5,6].

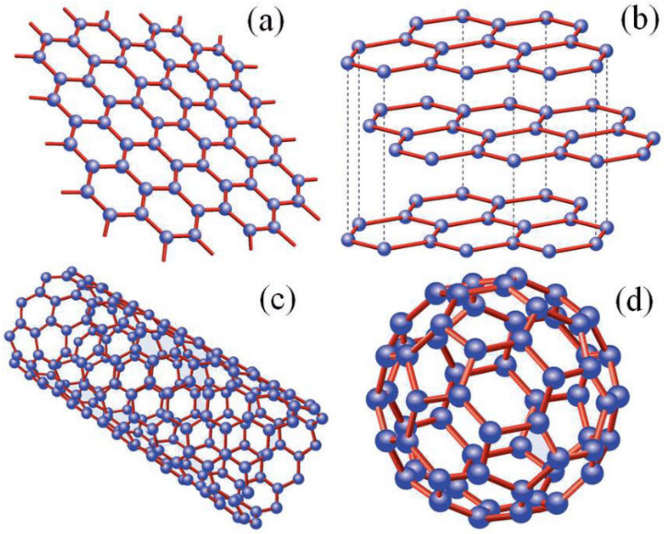

Figure 1. Structure of graphene and related structures. (**a**) Graphene structure 2D hexagonal lattice of carbons. (**b**) A-B-A stacked graphene layers. (**c**) Rolled-up cylinder of graphene. (**d**) C60 is a molecule formed by balling up graphene into a sphere, creating pentagons and hexagons in the lattice. It is named fullerene [7].

Composite materials can be synthesized by combining two or more materials to create a new one with added and improved properties compared to the original ones. Nanocomposites are composites that present one of their components in the nanometer scale (less than 100 nm). In that regard, graphene nanocomposites have gained much attention as they provide improved properties with very low concentrations of graphene, normally 1–3 wt.% [8].

Before delving into specific applications, it is essential to understand what makes graphene an attractive additive in composite materials (Table 1). Graphene exhibits extraordinary mechanical strength, approximately 200 times greater than steel, while being remarkably lightweight. Its high thermal conductivity enables efficient heat dissipation, making it ideal for electronic and energy storage applications. Furthermore, graphene boasts excellent electrical conductivity, which can significantly improve the performance of conductive composites. These unique properties allow for enhancing existing materials, offering improvements in performance, efficiency, and sustainability.

Table 1. Physical properties of graphene [9,10].

Physical Property	Value
Specific surface	2600 m^2/g
Young's module	0.5 TPa
Breaking stress	42 N m
Thermal conductivity	5000 W/m K
Electric conductivity	0.96×10^8 Ohms·m^{-1}
Refractive index at 670 nm	3.135
Absorption coefficient at 670 nm	0.897

Currently, electronics, energy, and biomedicine are three of the most relevant research fields, as they contribute to the rise of novel technological advances, improved sustainability, and healthcare. For instance, with the growing demand for smartphones and biomedical devices, the interest in interconnecting these three areas requires interdisciplinary efforts along with materials science to achieve progress in the well-being of society. Due to the properties mentioned above, graphene is an excellent candidate for its use in the selected applications. Hence, this review will explore the multifaceted roles of graphene and its composites in material science, particularly focusing on its contributions to energy storage systems, semiconductors, and biomedical applications.

2. Graphene and Graphene/Polymer Composites

The increase in demand for graphene has diversified the techniques for obtaining it to discover scalable and non-scalable methodologies at an industrial level. Table 2 presents a summary of these technical advantages and disadvantages. Graphene-based composites have experienced continuous advances in recent years. Until now, it has not been easy to obtain cheap, good-quality, large-scale graphene, although there is a lot of information about it. The most promising efforts and of great interest to the scientific community to achieve economical, quality, and large-scale production focus on electrochemical exfoliation processes because better graphene crystallization is obtained. However, this method still presents many challenges [11].

Graphene is one of the materials with the most synthesized methods. The problem of obtaining high-quality graphene with homogeneous thicknesses and dimensions that can be scalable still exists. Currently, the high-quality graphene has been obtained, but at a non-scalable level. However, high-quality graphene is not always required for certain processes, and depending on the customer's needs and budget, there are inexpensive and expensive methods. It is important to obtain graphene on a large scale for many applications that require it, such as nanoelectronics. However, existing methods must be refined and new methods developed. It has been found that plasma chemical vapor deposition using plasma and hydrothermal self-assembly can produce graphene in large quantities. These two methods are one of the most appropriate and have the most future for large-scale industrial applications [12].

Table 2. Methods to produce graphene.

Technic	Methods	Advantages/Disadvantages	Reference
Exfoliation	Adhesive tape	Achieving single layers typically requires multiple exfoliation steps	[13]
	Liquid-phase exfoliation	Low concentrationLarge energy requirement	[14]
	Electrochemical synthesis	Flake area, number of defects, and lake properties	[15]
Laser-Induced Graphene (LIG)		High electrical conductivity compatible with roll-to-roll manufacturing processes	[16]
Hydrothermal self-assembly		Environmentally friendly, low-cost, scalable for mass production	[17]
Epitaxy	Chemical vapor deposition using plasma PECVD	Reactants in the gas phase, elevated temperatures, van der Waals forces, scalable	[18]
	Spin coating	Gas over the substrate, moderate temperature	

On the other hand, graphene composites combine properties of graphene in a polymer matrix to improve certain properties, mainly mechanical and electrical properties [19], thermal stability [20], and barrier properties [21]. Graphene/polymer composites can be prepared using the most common techniques for polymer nanocomposite preparation: a simple solution process, a melting process, or in situ polymerization [22]. Due to its versatility, graphene has been used effectively in different applications, including as a reinforcing material in polymers for industrial applications, including anti-static materials, electromagnetic interference shields, and sensors. However, the conditions of high conductivity and mechanical properties of these materials are frequently difficult to balance [23].

Polymeric materials are thermal insulating materials with a thermal conductivity of less than 0.5 $W{\cdot}m^{-1}{\cdot}K^{-1}$, which is why they have been widely used. Because they have low thermal conductivity, a way has been sought to increase it, and graphene is a good candidate to achieve this. Qi-qi Bai and collaborators (2016) carried out a study in which they manufactured a composite material of polystyrene (PS) with graphene by two different methods, one of them by dissolving the PS and the second also by dissolving the PS and extrusion to obtain the material, finding that the thermal conductivity of the PS composite (1.03 $W{\cdot}m^{-1}{\cdot}K^{-1}$) increases by approximately 400% for PS (0.18 $W{\cdot}m^{-1}{\cdot}K^{-1}$). With this study, a significant increase in the thermal conductivity of PS is observed [24].

In another study, Gongqing et al. made a graphene/polymer composite material using two different methods, one of vacuum-assisted suction and the other a conventional dissolution process [25]. In a previous study, they observed that using paraphenylenediamine (PPD) could reduce and functionalize graphene oxide; starting from this structure, they prepared resistant 3D graphene architectures. The researchers used 3D graphene-PPD aerogels and infused them with epoxy monomers to create electrically conductive composites. Their findings indicated that a solution-molded epoxy composite with approximately 1.5% filler volume exhibited a yield strength of about 2×10^{-11} YE. However, through vacuum-assisted impregnation, the electrical conductivity reached 4×10^{-2} S/m with only around −0.21% filler volume, representing an increase of nearly 13 orders of magnitude compared to pure epoxy.

A study by Chang Il Kim et al. prepared three types of graphene with moderate functionality through the thermal reduction of GO to form six graphene/nylon composites. These composites showed enhanced electrical conductivity with a small amount of graphene added, and they were produced using the in situ method. In a standard procedure, an appropriate quantity of graphene was combined with 90.9 parts of caprolactam and subjected to sonication at 90 °C for 2 h. After adding 9.1 parts of aminocaproic acid as an initiator, the mixture underwent polymerization at 250 °C for 8 h. The polymerized compounds were then crushed into powder and dried at 80 °C under vacuum for 24 h to eliminate low molecular weight components. This study revealed an improvement in the electrical conductivity of the six graphene/nylon composite materials, and further enhancement was observed when the graphene underwent thermal treatments at elevated temperatures [26].

Vicenttic and collaborators showed a study of graphene production on sodium alginate cross-linked by laser induction. Sodium alginate, as is its viscosity, is stabilized with the cross-linking process, making it useful for different applications. The potential for laser-induced graphene from this substance has not been documented, opening up numerous opportunities for advancements in biological sensor electronics. For this work, we will only analyze the impact on the material's electrical resistance. This study shows different laser scanning speeds and resolutions. Figure 2 displays the electrical resistance of samples created at different laser scanning speeds. The variations are thought to be primarily caused by the effectiveness of cross-linking rather than the level of oxidation, as the oxygen content remains consistent across all samples [27].

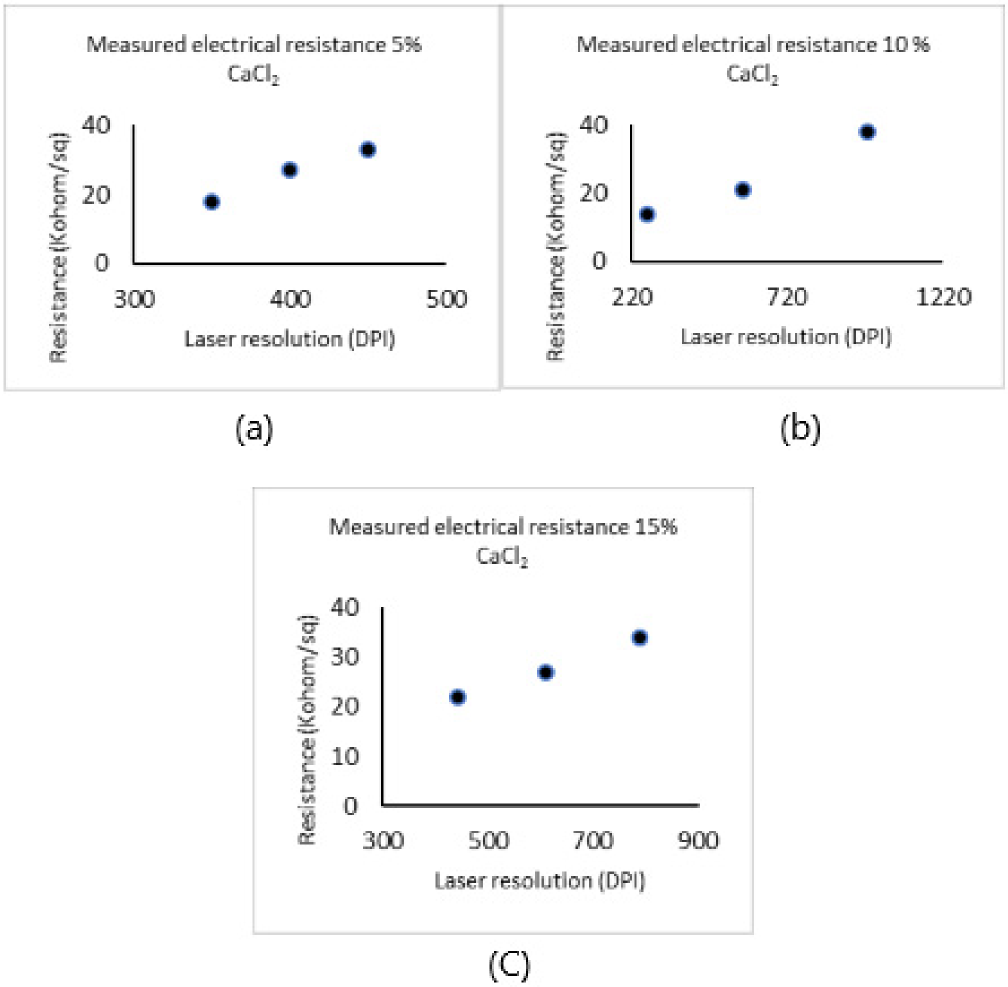

Figure 2. The measured electrical resistance of LIG. (**a**) Resistance measured at $CaCl_2$ concentration 5%. (**b**) Resistance measured at $CaCl_2$ concentration 10%. (**c**) Resistance measured at $CaCl_2$ concentration 15%. [27].

3. Applications of Graphene and Composites

Table 3 shows the main applications of graphene and composites, and more research is being conducted on applications such as photodetector, field effect transistor, and Schottky diode.

Table 3. Applications of graphene.

Graphene Applications	Reference
Field effect transistor	[28,29]
Shoctty diode	[30–32]
Antenna THz	[33]
Photodetector	[34]
Logic gate	[35]
Solar cell	[36]
Semiconductor	[37,38]
Sensor	[38,39]

3.1. Electronics and Sensors

The ability to control the electrical properties of a material utilizing the external application of a potential difference is the heart of modern electronics. On many occasions, it is this electric field effect that allows varying the charge concentration in a semiconductor and consequently changing the electric current through it [40]. Graphene has enormous potential for future applications in the field of electronics, mainly due to its physical and chemical properties, among which are: thermal conductivity of 4000 $W \cdot m^{-1} \cdot K^{-1}$, electrical conductivity of 0.96×10^6 $\Omega \cdot m$, mechanical resistance of 42 N/m, and light absorption of 2.3%. Moreover, an advantage over Si for electronics is that graphene is an intrinsic semiconductor, so it does not require any doping [28].

The semiconductor industry is a domain where graphene's distinctive characteristics shine. With the advent of modern electronics, the demand for materials that can facilitate faster processing speeds while consuming less power has skyrocketed. Graphene's high electron mobility allows faster transistors to develop, leading to more efficient integrated circuits. Interestingly, incorporating graphene into composite materials has made it possible to create flexible and transparent electronics. Such advancements open avenues for innovative applications in wearable technology and flexible displays; as industries increasingly seek lighter, more adaptable electronic devices, graphene composites may revolutionize product designs, making them more efficient and esthetically pleasing.

Additionally, researchers are investigating the potential of graphene-based field-effect transistors (GFETs), which could lead to the development of faster chips for computing and telecommunication. These GFETs promise to operate at higher frequencies than conventional silicon-based devices, thus positioning graphene as a crucial component in the future of semiconductor technology [2,29]. Graphene has been incorporated into different aspects of research processes and in our daily lives. Graphene has been used in flexible electronics such as televisions, curved screens, tablets, biocompatible sensors, stretch batteries, or mobile phones that change shape. More and more projects and prototypes of this type are seen.

Graphene is used as a two-dimensional semiconductor, and its composites have been shown to have significant potential in modern nanotechnology. Outstanding graphene properties have led to a growing interest in developing graphene or reduced graphene oxide coupled with semiconductors to obtain composites. These materials can be obtained through synthesis methods like hydrothermal [41], solvothermal [42], self-assembly [43], sol–gel [44], and chemical precipitation [45], among others.

Hongfei Li et al. [30] studied the interactions of ZnO/graphene junctions and ZnO/graphene/graphene interactions in which they found that ZnO/graphene composite materials exhibit semiconducting to metallic transitions, this transition between Schottky to ohmic contacts. The findings indicate that the movement of carriers in ZnO/graphene nanocomposites can be triggered by the application of an external electric field to effectively control the type of contact (Schottky/Ohmic). The presence of Schottky contacts confirms the distinct nonlinear I–V characteristics of ZnO graphene nanocomposites.

Yimeng Li et al. [31] carried out a study of a metal oxide-based semiconductor using a NiO/graphene/4H-SiC composite material where a double Schottky barrier was achieved and the concentration of holes was achieved by modulating the gate voltages, allowing this device to operate both as a photoconductive detector and as a Schottky photodiode. The graphene on top of the semiconductor constructs a highly sensitive emerging photodetector with internal gain. Due to the graphene/semiconductor interface bonding, one type of photoexcited carrier moves toward the graphene, and the other carriers remain in the semiconductor.

In previous studies, Elif Oz Orhan et al. [32] studied the response of graphene deposition on a Schottky diode. This type of diode is commonly used as a signal and switching conditioner, metal oxide semiconductor logic gates (CMOS), and transistor–transistor logic (TTL). They carried out a deposition of graphene on the p-type silicon, performing laser treatment on the surface where they observed a change in the morphology of the film. Later, they used chemical vapor deposition techniques using radiofrequency plasma to add the graphene. The results showed that the laser treatment caused an increase in the height of the Schottky barrier and decreased the leakage currents under a reverse bias voltage of the diode Figure 3.

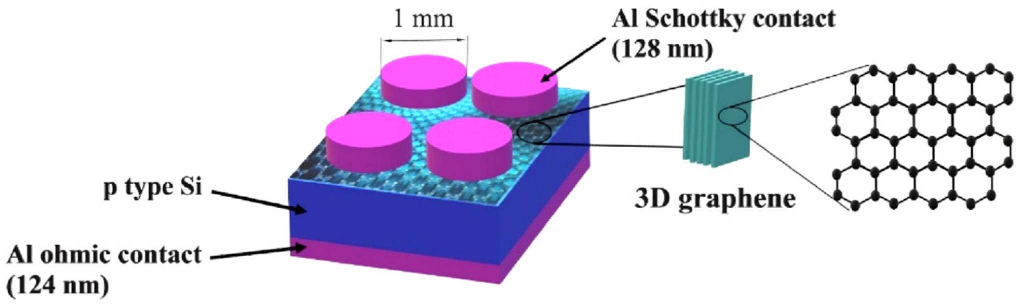

Figure 3. Schematic of p-silicon Schottky diode decorated with graphene [32].

On the other hand, it has been sought that graphene semiconductors can be used in the design of reconfigurable antennas in the terahertz (THz) range; such is the case of Negri et al., [33] discovered that the effectiveness of graphene-based terahertz (THz) devices is significantly hampered by the ohmic losses of graphene. They suggested using hybrid metal–graphene structures in certain situations to address this issue. They examined this approach to enhance radiation optimization for improving an antenna. They proposed a metal–graphene metasurface hybrid for the antenna, which consists of a network of square metal patches interspersed with a complementary graphene strip grid. This study shows that appropriate unit cell selection achieves a satisfactory balance. In addition, different reconfigurations and addressing of the antenna can be achieved, and future applications in wireless communications can be found.

The environmental sustainability and flexibility of photodetection processes have taken on increasing interest, focusing on support materials or substrates because traditional substrates, such as silicon wafers, demand high costs and complicated techniques for their manufacturing in a study reported in 2024 by Malik et al. [34] introduced a spray lithography technique for commercial paper. They developed a spray lithography substrate comprising single-layer graphene, carbon nanotubes, and perovskite quantum dots on a paper substrate. Due to the photoconductive gain mechanism, the resulting device demonstrated a high external responsivity of about 520 $A \cdot W^{-1}$ at 405 nm with a bias voltage of less than 1 V. Their study's paper photoconductor exhibited an external responsivity of 520 $A \cdot W^{-1}$ under 405 nm illumination with an illumination voltage of less than 1 V.

In 2023, Kumas et al. [35] utilized terahertz and multi-terahertz spectroscopy to examine the optical characteristics of three-dimensional graphene (3D G) across a frequency range of 0.15 to 10 THz. Special attention was paid to the electromagnetic shielding, stealth, and absorption capacity of the 3D G, which was annealed with temperature variations of up to 1300 °C. The system can act as a hidden element (without treatment) or absorber (with treatment at 750) of THz and a protective layer (with treatment at 1300 °C) in a range from 0.2 to 7 THz. One of the advantages of these materials is that they can be stacked to combine their properties.

Another study by Malik Abdul Rehman et al. [36] demonstrated the application of a solar cell on an n-type silicon semiconductor, in which they performed chemical vapor deposition of an aluminum oxide coating. This Al_2O_3 interfacial layer acts as a hole carrier layer that minimizes the dark current, allowing depolarization of the photoreductant and reducing recombination. Furthermore, by the same method, the deposition of vertical graphene nanostructures continues, where the photo response of the device under U.V. lighting was measured, obtaining a sensitivity response or response capacity of a spectral photodetector, which is the variable that relates to the capacity of current produced by each wavelength of light intensity, the reported one being 1.196 $A \cdot W^{-1}$, which is considered an appropriate response for this type of semiconductor.

Graphene as a semiconductor does not have an intrinsic bandgap. Jian Zhao et al. [37] carried out in 2024 a study in which they achieved an epitagraphene material on monocrystalline silicon carbide substrates, which has a bandgap of 0.6 eV and mobilities greater than 5000 $cm^2 \cdot V^{-1} \cdot s^{-1}$, which represents a value 10 times greater than that of silicon and 20,280 times greater than that of other semiconductors.

In this same sense, Jungyoon Kim et al. [38] developed a field-effect transistor that works as an environmental sensor that allows the sensing of nitrate ions in water. This was performed using an electrochemical membrane model, where graphene produced by chemical vapor deposition (CVD) and kaempferol (KMPR) was used for this process. To achieve the selectivity of the sensing, nitrate ionophores, PVC, and plasticizer were included in the transistor, which was applied directly to the graphene surface. Thanks to the resulting material, the detection of nitrates could be observed without interference of other ions.

The electrical conductivity of graphene has allowed its use in analytical applications, such as the case of electrochemical techniques, specifically voltammetry, which enables the use of graphene as an electrode, just as reported by Andrzej Peplowski et al. [39]. They used graphene as an electrode to verify its sensitivity and linearity in low-concentration samples. For this purpose, the electrodes were manufactured using a screen printing technique. At first, the connection paths were printed on a polymethyl methacrylate sheet using L-121 silver polymer paste. Then, the graphene layer was added, which consisted of a paste prepared by drying at 150 °C for 1 h. The device was tested on a simulated tear film containing NaCl, $NaHCO_3$, KCl electrolytes, proteins, ascorbic acid, and/or glucose. The measurements were initially carried out above the physiological level concentrations, observing that the analyte concentration limited the electrode's reaction speed; when carrying out the tests below physiological concentrations, a better electrode behavior was observed, presenting linearity (correlation coefficient of 0.9971).

3.2. Energy Storage

One of the most promising areas for applying graphene is energy storage, particularly in batteries and supercapacitor technologies [4,46]. Traditional lithium-ion batteries, while prevalent, face challenges such as limited capacity and reduced charging times. Integrating graphene into electrode materials has shown a marked improvement in these aspects. For instance, graphene oxide can increase the surface area of electrodes, leading to higher charge storage capabilities [46]. Moreover, graphene's conductivity enhances electron transport within the electrodes, facilitating faster charge and discharge cycles. Supercapacitors are recognized for their ability to charge and discharge quickly, and they are further enhanced by adding graphene. The integration of graphene with other substances has led to the development of hybrid supercapacitors that offer increased energy density while maintaining fast charging and long-term durability. Table 4 shows the main applications of graphene in energy storage. These advancements position supercapacitors infused with graphene as a practical substitute for conventional batteries, particularly in scenarios that demand rapid energy release, such as regenerative braking in electric vehicles [47].

Table 4. Applications of graphene in energy storage.

Graphene Applications	Reference
Capacitor	[47,48]
Battery cathode	[49–52]
Battery anode	[53–55]
Photovoltaic electrode	[53–55]
Paper-based electrode	[55]
Conductive ink	[56]

The development of lightweight and flexible consumer electronics has led to the creation of a flexible fiber supercapacitor by Vijaya Sankar et al. This supercapacitor is designed using covalently grafted reduced $CoFe_2O_4$/graphene oxide/polyaniline. The configuration of this supercapacitor is $CoFe_2O_4/rGO/PANI = \beta - Co(OH)_2$. It offers a maximum energy density of 270×10^{-8} $W \cdot h \cdot cm^{-1}$ and a power density of 625 $\mu W \cdot m^{-1}$. Additionally, electrochemical cyclic stability was tested at 5 mA in a 1 M KOH electrolyte for 1000 cycles, resulting in some loss of capacitance. The manufactured supercapacitor demonstrates a Coulombic efficiency of 87% in 1000 cycles, which is lower due to the faradaic charge storage mechanism and redox irreversibility [48].

The use of graphene in energy storage devices is highly valuable. Still, its application in direct use is challenging due to its large surface area and flexibility, leading to excessive electrolyte consumption and low Coulombic efficiency [49]. Therefore, it is crucial to modify graphene, coat it with another material, or combine it with another material to create a composite material. For example, in 2023, Dai et al. [50] synthesized a composite material of reduced nickel silicate and graphene oxide (GO) to enhance lithium-ion storage. They achieved this by anchoring nickel silicate on reduced GO using a hydrothermal method, forming a network with good electrochemical performance as a lithium-ion battery anode. The composite material exhibited an initial capacity of 1525.7 $mA \cdot h \cdot g^{-1}$. and retained a capacity of 815.5 $mA \cdot h \cdot g^{-1}$ after 50 cycles, with an average capacity of 415.8 $mA \cdot h \cdot g^{-1}$ at a current density of 5000 $mA \cdot g^{-1}$. It also showed high stability with a 423.4 $mA \cdot h \cdot g^{-1}$ capacity after 1000 cycles [50]. Additionally, in 2023, Polishchuk et al. [51] demonstrated the enhancement of electrical parameters in lithium-ion (Li-S) batteries by incorporating graphene into sulfur electrodes. The use of graphene resulted in a significant positive impact, particularly evident during the voltammetry cycle, leading to a two-fold increase in the current value at the cathode and anode peaks when compared to electrodes without graphene.

On the other hand, Zhe-Yuan Wu et al. [52] performed a doping of silicon with graphene to obtain electrodes from waste silicon from the photovoltaic industry because it is an interesting ecological proposal to use them as anodes in lithium-ion batteries. Silicon in these conditions is deficient for this activity. However, with the help of graphene, better conductive stability is possible for this purpose. In addition, boron-doped graphene improves the transport kinetics of lithium ions due to the decrease in the barrier potential.

The boron-doped silicon–graphene composite exhibits increased stability due to the doping effect and the carbon matrix, with a charge retention of 70% after 80 cycles at 500 $mA \cdot g^{-1}$. Additionally, it demonstrates a high capacity of 850 $mA \cdot h \cdot g^{-1}$ and maintains a cycle retention of 76.5% after 180 cycles at 225 $mA \cdot g^{-1}$. These electrochemical performance results suggest that boron-doped silicon and graphene effectively enhance the anode's lifespan, as a study indicates.

In 2021, Wen-Jie Meng [53] studied silicon-based anodes for lithium-ion batteries, as depicted in Figure 4. This study utilized defective reduced graphene oxide (DRGO) to support silicon nanoparticles (SiNP), leading to enhanced reversible capacity and cyclic performance. They created a cage-shaped shell to encase SiNPs with space between layers. To reduce defects, glucose was used to repair graphene oxide (GO) and generate DRGO.

The integration of SiNPs into defect-repaired RGO cages (Si@DRGOC) resulted in a gravimetric capacity of 2678.4 mA·h·g^{-1} at 100 mA·g^{-1}, with a coulombic efficiency exceeding 98% as a lithium-ion battery anode. The Si@DRGOC electrode also exhibited reasonable rate capability, with capacities of 1284.5 mA·h·g^{-1} at 2 A·g^{-1} and 2002.7 mA·h·g^{-1} at a current density of 100 mA·g^{-1}. This well-designed structure offers a promising method for producing anode materials in high-performance lithium-ion batteries.

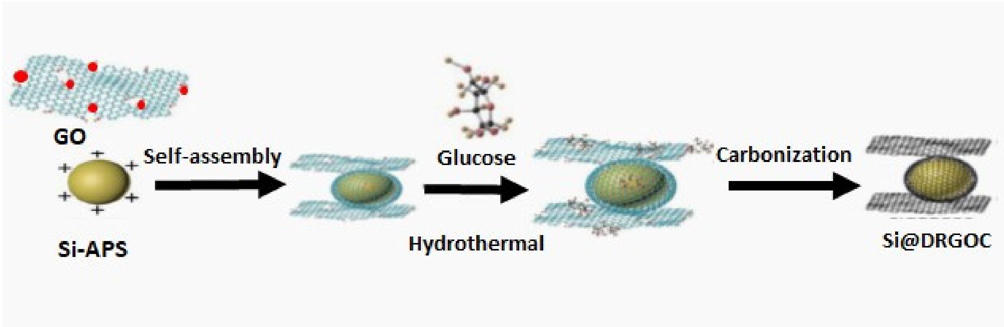

Figure 4. Representation of reduced graphene coating silicon nanoparticles. Reproduced with permission [53].

Young Seul Cho et al. [54] obtained a composite material from silicon and activated graphene used as an anode in lithium-ion batteries. The manufacturing process of composite flakes was carried out by preparing the silicon nanoparticles and then adding the activated graphene nanoparticles. Finally, the composite flakes were formed using an oven with different etching times for the activated graphene, thus obtaining a material with two critical properties: porosity and flake size. The results showed that the higher the porosity, the higher the lithium diffusion; it was observed that the conductivity increases as the size of the flake increases, which represents a good option for the application proposed by the authors.

In the realm of energy supply processes, graphene shows great promise. In 2023, D.-P. Argyropoulos et al. [55] created an electrode for lithium-ion cells. They blended polylactic acid and graphene, followed by hot pressing to produce the electrode. The composite material of PLA/graphene exhibited an initial specific gravimetric capacity of 858 mA·h·g−1 during the first lithiation and 217 mA·h·g^{-1} during the first de-lithiation, demonstrating a low initial Coulombic efficiency of 25.3%. This decreased initial Coulombic efficiency is likely due to the unevenness of the electrode surface and the high macroporosity performance. In the second cycle, the electrode demonstrated capacities of 308 mA·h·g^{-1} and 253 mA·h·g^{-1} for lithiation and de-lithiation, respectively, with an improved coulombic efficiency (CE) of 82.1%, indicating its potential as a material for this application.

The demand for lithium-ion batteries has been strong, but they have energy limitations that cannot meet the growing demand for these devices. The potential use of lithium–carbon dioxide batteries seems promising, but two challenges must be addressed. Firstly, the difficulty of uniformly controlling the nucleation and growth of Li-CO_2 during discharge, and secondly, the challenge of decomposing Li_2CO_3 during charging. While metallic crystals like ruthenium and iridium have been suggested to address these issues, their high cost makes them less feasible. The continuous challenge lies in developing a cost-effective and highly efficient cathode catalyst for the reversible formation and decomposition of Li_2CO_3. In 2021, Biao Chen et al. [57] conducted a study based on theoretical calculations. They employed CO_2 to enhance the catalytic activity of traditional nitrogen-doped graphene, containing a high total content (72.65%) of pyridinic N and pyrrolic N, showing high catalytic activity in CO_2 evolution and reduction reactions, thus facilitating the reversible conversion of Li_2CO_3 formation and decomposition. As a result, the designed cathode demonstrates a minimal voltage gap of 2.13 V at 1200 mA·g^{-1} and exhibits long-term cycle stability, with only a slight increase in voltage gap of 0.12 V after 170 cycles at 500 mA·g^{-1}.

In their research, Kristiāns Čerņevičs et al. [56] studied the impact of "bite" defects on the electronic transport properties in chevron-type reduced graphene (GNR), discovering that the position of the defects determines the level of dispersion. Building on their previous work with individual GNRs, the team intentionally introduced engineered defects into two nanostructures to create fundamental nano-electronic components. They first developed a switch using three laterally fused fluorenyl–chevron GNRs and added a pair of "bite" defects to enable switching between four binary states representing different current pathways. They then showed that strategically placing a pair of "bite" defects can increase the conductance between two wires in a triple-chevron GNR junction. They explained how including "bite" defects influence the transport properties in chevron-like nanostructures and provided guidance on designed nanoelectronics components. Another notable study involving graphene as an energy storage medium was conducted by Yanik et al. [58], who successfully produced a supercapacitor for energy storage. They created a composite material by blending graphene with polypyrrole or magnetic polypyrrole, resulting in conductive ink. They used this ink to assemble a supercapacitor with copper sheets, a Teflon separator, and an electrolyte. The key outcome of this process was a 255 $F{\cdot}g^{-1}$ capacitance.

The growing need for flexible components in electronics and optoelectronics has allowed the realization of novel applications such as flexible displays, electronic textile elements, and distributed sensors, among others; still, they are not fully available on the market due mainly to their slow development. To overcome this limitation, efforts have been dedicated to manufacturing flexible energy storage devices; in this sense, Yao et al. [59] conducted research in 2017 to elucidate this field of research and development. Once again, graphene's versatility in producing paper-based electrodes for energy storage becomes visible. These systems behave as flexible energy storage films and, for more than a decade, have been a widely studied alternative with great potential for the future of energy storage, as seen in Figure 5.

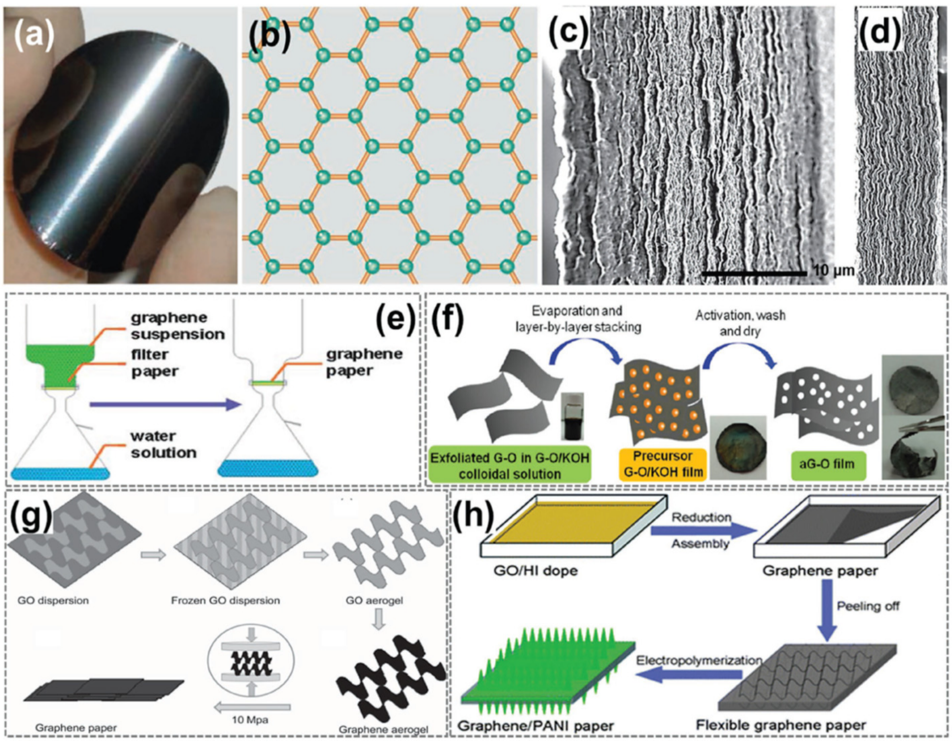

Figure 5. The manufacturing of graphene-based paper electrodes for energy storage involves four different approaches. (**a**) The first approach involves creating flexible graphene paper by carefully stacking graphene sheets. (**b**) In the second approach, carbon atoms of graphene are connected through

sp^2 hybridization, as indicated by the orange lines linking the green dots representing carbon atoms. (**c**) The third and (**d**) fourth approaches are illustrated by SEM images showing the cross sections of the obtained liquid electrolyte-mediated chemically converted graphene films with different volume percentages of H_2SO_4. (**e**) The fifth approach involves obtaining graphene paper through graphene dispersion and vacuum filtration. (**f**) The sixth approach is depicted in a schematic showing the experimental steps of activated reduced film and the graphene paper formation process. (**g**,**h**) The final approach is outlined in a scheme illustrating the graphene formation process of PANI paper. Reproduced with permission [59].

3.3. Medical Applications

Beyond electronic and energy applications, graphene has emerged as a pioneer in biomedical fields. Its biocompatibility and large surface area make it suitable for drug delivery systems. By functionalizing graphene with specific biomolecules, researchers can create targeted delivery mechanisms that enhance the efficacy of drugs while minimizing side effects. This capability is particularly beneficial in treating cancer, where precision medicine is becoming paramount. Furthermore, graphene can be used in biosensors, where its high sensitivity can detect biomarkers at low concentrations, thus facilitating early diagnosis of diseases. The ability to integrate graphene with existing medical devices opens possibilities for real-time monitoring of patient health. Another notable application involves using graphene in tissue engineering. Table 5 summarizes some of the most important applications of graphene in the biomedical area. Mechanical properties and biocompatibility create a conducive environment for cell growth and differentiation, making it an effective scaffold material in regenerative medicine. Ongoing research aims to develop graphene-based structures that mimic natural tissues, enhancing the prospects for successful implants and prosthetics [58,60].

Table 5. Applications graphene in biomedicine.

Graphene Applications	Reference
Artificial muscle	[61–65]
Biomedical sensor	[66–69]
Bactericide	[69]
Pressure sensor	[70,71]
Tissue regeneration	[72]
Protein builder	[73]

Graphene exhibits several properties throughout this manuscript, including a large surface area, biocompatibility, ease of functionalization, and adsorption capacity, among others. As a result, it finds extensive use in biomedicine, currently being utilized in tissue regeneration, tendon regeneration, and disease diagnosis [58]. Artificial muscle refers to a soft actuator capable of mimicking biological muscles to execute contractions, twisting, and other modes of action [61]. Furthermore, there is growing interest in 3D printable artificial muscles [62].

Chae-Lin Park et al., [63], documented the enhanced performance of an artificial muscle created from fern and dual nanocarbon structure. The carbon nanoroll and carbon nanotube (CNS/CNT)-(CCYM) yarn muscles demonstrated improved actuation stroke, work capacity, power density, and energy conversion efficiency. These improvements were 1.4, 1.4, 4.8, and 4.3 times higher, respectively, compared to the pristine CNT yarn muscles. An important consideration in muscle development processes is incompatibility. In 2016, Matin Mahmoudifard and team conducted a study wherein they integrated graphene and graphene oxide into bioactive polymers such as polyacrylonitrile (PAN) and polyaniline (PANI) to enhance their conductivity and biocompatibility. Muscle satellite cells were cultured after enrichment using a preplating technique, and their behavior was analyzed.

Proliferation and differentiation were evaluated using the Cell Proliferation Kit (MTT), real-time polymerase chain reaction (PCR) assays, and 4′,6-diamidino-2-phenylindole (DAPI) staining. Cells cultivated on PAN/PANI-CSA/G composite nanofibrous material displayed increased proliferation and differentiation values compared to other groups, including PAN/PANI-CSA/GO and PAN/PANI-CSA scaffolds [64].

Similarly, exploring the potential of using antimicrobial coatings for implants. For instance, in 2023, Rico-Romo applied graphene to a medical-grade cobalt–chromium alloy (CoCr) surface using radiofrequency plasma-enhanced chemical vapor deposition (RF-PECVD) with Origanum Vulgare (oregano) as the source material. Their research focused on the biocompatibility and antibacterial properties of CoCr-Gr. Initial tests confirmed that the material is biocompatible, promotes cell adhesion, and stimulates the proliferation of RAW 267.4 macrophage cells. Additionally, it exhibited antibacterial properties against Staphylococcus aureus and Pseudomonas aeruginosa, inhibiting the latter's growth. These findings suggest that CoCr-Gr could be an antibacterial coating for implantable devices [65].

Conversely, integrating graphene with functional materials and biological recognition elements has led to advancements in electrochemical sensors for detecting electrophysiological signals and biochemical analytes. In 2024, Zengyu Ma [66] conducted a study that showcased progress in flexible substrate sensors assisted by graphene for monitoring human movement. This study highlighted the use of these sensors in tracking joint movements, breathing, and cardiovascular parameters. The authors focused on the performance of graphene-based sensors and noted that it is largely influenced by the morphological characteristics of graphene films and structures. For instance, in 2023, Derrick Butler et al. [67] developed graphene films in solutions for the electrochemical control of extracellular nitric oxide released by breast cancer cells. They created an electrochemical sensor based on graphene ink, processed in a solution modified with fibronectin using a manufacturing method involving spin coating and hot plate annealing. Real-time amperometry measurements confirmed nitric oxide production with graphene electrodes functionalized with fibronectin.

Also in 2024, Shafiul Islam et al. [68] carried out the manufacture of a large area of titanium nitride/graphene (TiN-G) electrode, which was produced by the electrochemical deposition method of graphene oxide on titanium nitride nanorods; this electrode was tested by cyclic voltammetry for the detection of ascorbic acid, dopamine, and nitrate ions. Comparing it with a titanium nitride nanorod electrode, the results shown in this study showed that the TiN-G electrode has better electrochemical properties than the titanium nanorod electrode in addition to having a better electrochemical response to the analyzed analytes.

Jacob Wekalao et al. [69] developed and analyzed a sensor to detect malaria early, a life-threatening disease spread by mosquitoes carrying parasites. They applied ring-shaped graphene and cross-shaped formations on a glass base to achieve this. The sensor can enhance its sensitivity by adjusting how light and matter interact. Even with slight changes, this sensor accurately detects 300 GHz/RIU, as indicated in reference.

Because graphene oxide emerges as a potential bactericidal, Büşra Oktay [70] carried out the preparation of quantum dots of silver nanoparticles with graphene oxide to test the bactericidal effect of this compound, determining that the manufactured material exhibits a photocatalytic behavior when exposed to UV light or sunlight so it can be used in water treatment plants or even in medicine.

The investigation of polymer/graphene compounds for detecting various analytes is ongoing. For instance, in 2020, Zhu Jing et al. [71] developed a pressure sensor using graphene and PDMS (polymethyl siloxane). The graphene is supported by an PDMS sponge skeleton. This sensor exhibits high elasticity with a deformation capacity of up to 85%, high sensitivity at 0.075 K^{-1}, a wide response range of 0–50 KPa, and high stability based on a 2000-cycle pressure test. The sensor can primarily determine blood pressure, heartbeats, and human movements such as finger flexion, elbows, and squats. This sensor's consistent responses and stability are attributed to the interaction between the PDMS sponge and graphene. Apart from its application in various sensors, the potential use of graphene in medicine is promising. Through functionalization, it can be utilized for drug transportation, prostheses creation, disease treatment improvement, and cell and tissue regeneration.

Karalca et al., in 2023, [72] carried out a study in which the role of graphene and nanocomposites in medical applications was analyzed, where they visualized it as a material used in biosensors for determining diseases. They were envisioning a new era in healthcare standards. Figure 6 shows the great potential that graphene electronics and your derivate can achieve in this field.

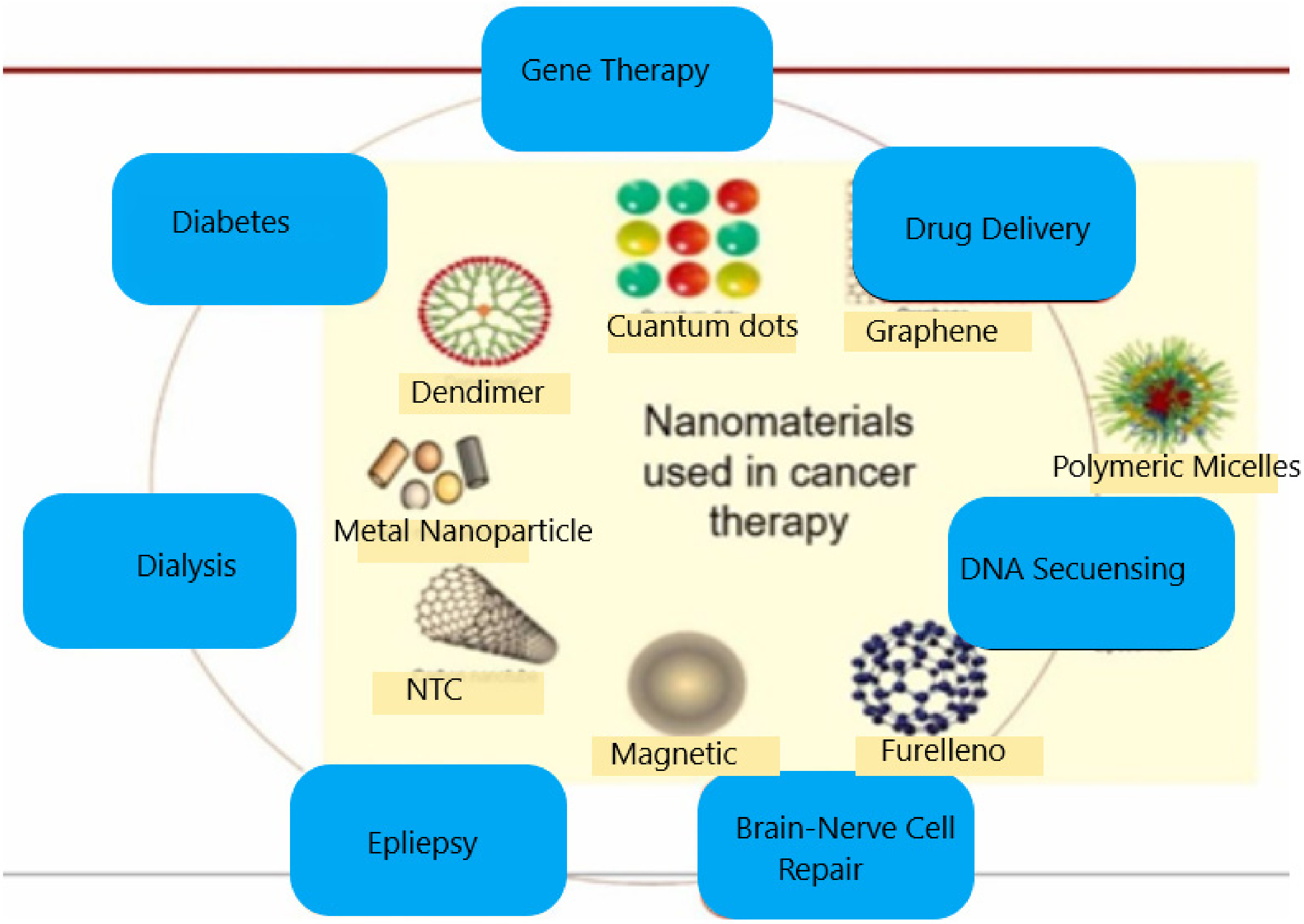

Figure 6. Graphene application in medicine. Reproduced with permission [72].

Research has recently focused on graphene, leading to the development of new methods for synthesizing graphene, making the material readily available in the market. Additionally, graphene derivatives, such as GO and rGO, have garnered increased interest for their applications. Graphene has been found to interact with proteins, which are the body's building blocks, affecting their secondary structure, functional groups, or through physical adsorption. On the other hand, GO's oxygen-containing groups allow for the immobilization of biocatalysts without the need for surface adjustments or coupling reagents. Gene delivery, which involves introducing foreign DNA into cells, provides an alternative method for treating genetic diseases. For gene delivery purposes, modified GO is used. Polyethyleneimine (PEI) modifies the surface of GO sheets to prepare them for cellular gene delivery through covalent conjugation and electrostatic interaction for plasmid (pDNA) stacking. In Figure 7, GO is covalently linked to the linear chain.

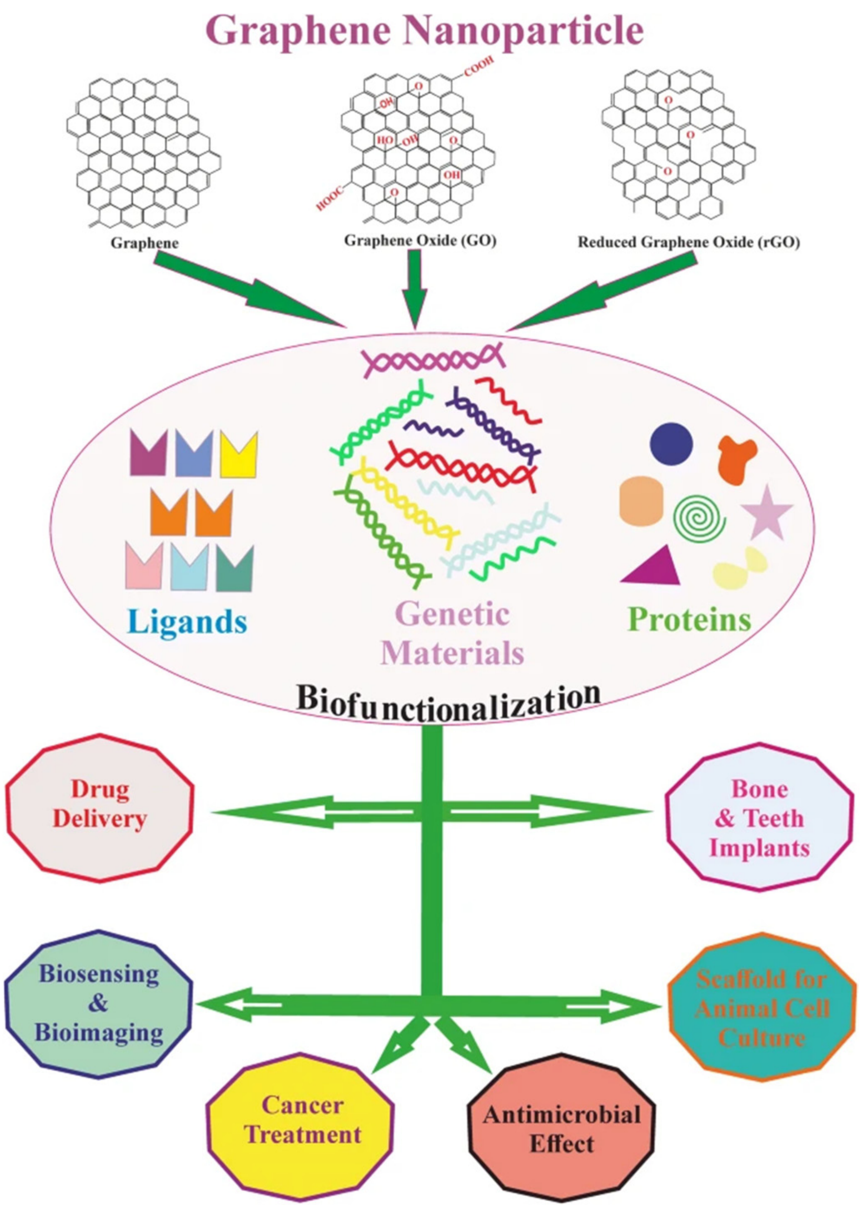

Figure 7. Graphene, GO, and rGO applications for medicine and biology applications [73].

The emergence of a new approach to tissue and regenerative medicine involving graphene-based materials is due to the limitations faced by traditional organ or tissue implantation and/or grafting methods, especially in light of the shortage of organ and tissue donors. Bone tissue engineering, aimed at promoting bone regeneration, offers a promising solution for the quicker healing and reconstruction of extensive bone defects, and graphene and its derivatives have a broad spectrum of applications in this field. An illustration in Figure 8 depicts one such application, where a three-dimensional rGO biomaterial adorned with a casein/polypyrrole phosphopeptide matrix, created through electrospinning and exhibiting remarkable hydrophilicity and water absorption capacity, was self-assembled on the scaffold's surface to facilitate the cost-effective formation of hydroxyapatite [73].

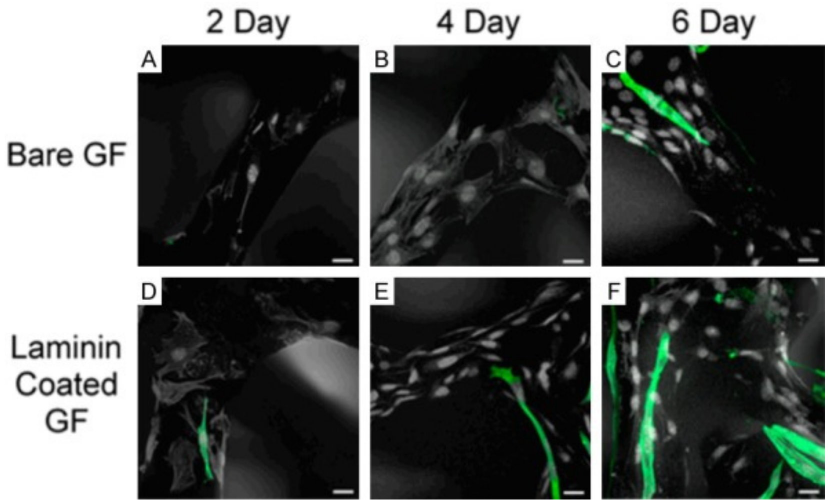

Figure 8. Immunofluorescence was used to observe MHCs as an indication of C2C12 differentiation. C2C12 cells were differentiated on uncoated glass coverslips (**A**–**C**) for 2, 4, and 6 days and on glass coverslips coated with laminin (**D**–**F**) for 2, 4, and 6 days. The scale bars in all images represent 20 µm. This image is reprinted with permission from a previously published source [74].

Graphene nanoplatelets in biomedical applications are emerging as a promising material, especially in regenerative medicine. We mention the study by Fontana Nicoletti et al. [75], which, in 2024, evaluated graphene nanoplatelets (UGZ 1004), focusing on their physical properties, cytotoxicity, intracellular interactions, and, in particular, their effects on mesenchymal stem cells (MSCs), Figure 9. They observed that this material can improve the self-renewal capacity of MSC, thereby ensuring a robust and long-lived function of the cells. Likewise, a negative process is observed in the genes associated with the development of tumors, including CCND1 and TFDP1.

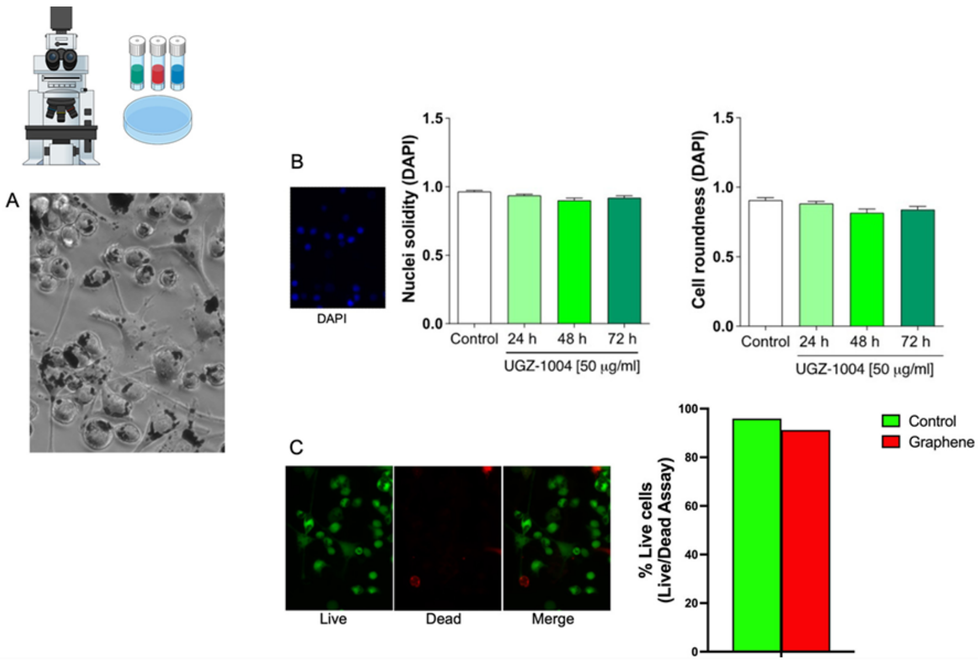

Figure 9. The interaction and survival of cells inside the cell. (**A**) BV2 microglia cells were cultured with the 648 UGZ1004 preparation. Graphene nanoplatelets were internalized, and the regular growth and shape were maintained (×40 magnification). (**B**) A graph displaying nuclei solidity and cell roundness marked by DAPI. (**C**) Live/dead test demonstrating cells stained green (indicating cell viability) and red stains (indicating dead cells) [75].

4. Conclusions and Outlook

This paper presents a sample of the benefits and advantages of graphene as a promising composite material for electronic applications for different purposes. In addition, it presents the most important characteristics of a semiconductor and why it becomes versatile for constructing sensors and other electronic devices. As explained, due to their conductive capacity, it is a material that can displace or improve current technologies, especially in electronics. It can be used in sensor applications where it is required to know a disturbance in the environment and convert it into the reading of a variable of interest, which is of great importance in medical applications.

Graphene-based composites have experienced continuous advances in recent years. Although graphene is one of the materials with the most methods to obtain, there is still a need to make them more efficient and economical and discover new options to produce high-quality graphene at a scalable level, which is the biggest challenge. One of the most promising techniques for obtaining graphene at an industrial level, but not without first carrying out more cutting-edge research, solving the intrinsic problems of each method, and making the process more efficient. According to the evaluation carried out, chemical vapor deposition using plasma and hydrothermal self-assembly are the techniques that already have a future in being scalable.

As seen in the works reported here, there is a growing interest in using graphene in batteries due to the growth in the use of portable electronic devices where batteries with greater charge capacity and energy density are increasingly required. Also, all the advances with graphene promise to be viable in flexible electronic device applications, in the construction of transistors, and in piezoelectric devices. Thus, talking about the graphene involved, sensors, flexible electronics industry, batteries, and supercapacitors development. At the same time, these composites and the generation of interfaces between their components often infer material morphology, electron transport mechanism, etc., so the thermoelectric performance can be further improved as the research progresses.

Although composite materials based on graphene are currently one of the most exploited lines of research and have achieved high properties in semiconductors, energy storage devices, and medical applications, the underlying mechanism in composite material formation must be clarified. Many variables still need to be clarified so that the development, preparation, and efficiency of devices for their application are timely since research and their application in daily life still need to be converged. Therefore, further improving energy storage efficiency and pinpointing application scenarios while maintaining flexibility and mechanical properties is necessary. To enhance the performance of graphene-based composites and explore in depth the mechanism of composite formation, researchers and industry should focus on designing and improving the most promising and useful composites in different areas of interest, such as some of those mentioned in this review. Specifically, looking for the optimization of conductive and lightweight materials improved with graphene, improving energy storage devices, and focusing on sensors (sensing devices in the disturbance in the environment) to be introduced into the human body.

Author Contributions: F.J.E.-H. and P.A.F.-S.: investigation and writing—original draft. contributed equally to this paper. L.F.M.-C.: writing—review and editing. F.J.G.: supervision and writing—review and editing. G.S.-A.: investigation and writing—review and editing. F.A.-B.: writing—review and editing. R.I.N.-C.: supervision and writing—review and editing. M.H.: writing—review and editing. This is a review where no new data was created, but an analysis of the information was carried out by the authors, and the required permissions for the publication of images were obtained. All authors have read and agreed to the published version of the manuscript.

Funding: This research did not receive external funding in its development.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding authors.

Acknowledgments: The authors thank the Universidad Autonomous University of Coahuila (UAdeC), the Faculty of Chemical Sciences, and the Ph.D. degree Program of Materials Science and Technology.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Titirici, M.-M.; White, R.J.; Brun, N.; Budarin, V.L.; Su, D.S.; del Monte, F.; MacLachlan, M.J. Sustainable carbon materials. *Chem. Soc. Rev.* **2015**, *44*, 250. [CrossRef] [PubMed]
2. Karthik, P.S.; Himaja, A.L.; Singh, S.P. Carbon-allotropes: Synthesis methods, applications and future perspectives. *Carbon Lett.* **2014**, *15*, 219. [CrossRef]
3. Kim, C.-H.; Hlaing, H.; Kymissis, I. A macroscopic model for vertical graphene-organic semiconductor heterojunction field-effect transistors. *J. Org. Electron.* **2016**, *36*, 45. [CrossRef]
4. Sun, W.; Yu, S.; Tang, M.; Wang, X. Friction and Wear Properties of Graphene /Epoxy Composites. *Earth Environ. Sci.* **2021**, *706*, 012038. [CrossRef]
5. Gaidukevic, J.; Barkauskas, J. Advanced Technologies in Graphene-Based Materials. *Crystals* **2024**, *14*, 769. [CrossRef]
6. Nguyen, B.H.; Nguyen, V.H. Promising applications of Graphene and Graphene-based nanostructures. *Adv. Nat. Sci. Nanosci. Nanotechnol.* **2016**, *7*, 15. [CrossRef]
7. Neto, A.H.C.; Guinea, F.; Peres, N.M.R. Electronic states and Landau levels in graphene stacks. *Phys. World* **2006**, *19*, 33. [CrossRef]
8. Ibrahim, A.; Klopocinska, A.; Horvat, K.; Hamid, Z.A. Graphene-Based Nanocomposites: Synthesis, Mechanical Properties, and Characterizations. *Polymers* **2021**, *13*, 2869. [CrossRef]
9. Pfc. Angel Luis Valverde Guijarro (BIGBANG.nucleares.unam.mx) 08 de junio de 2018. Available online: https://bigbang.nucleares.unam.mx/~jimenez/FAMC/TrabajosFAMC2018/Gordillo_Hansel_Grafeno.pdf (accessed on 16 October 2024).
10. Yang, K.; Wu, C.; Zhang, G. A state of review for graphene-based materials in preparation methods, characterization, and properties. *Mater. Sci. Eng. B* **2024**, *310*, 117698. [CrossRef]
11. Liu, F.; Wang, C.; Sui, X.; Riaz, M.A.; Xu, M.; Wei, L.; Chen, Y. Synthesis of graphene materials by electrochemical exfoliation: Recent progress and future potential. *Carbon Energy* **2019**, *1*, 173–199. [CrossRef]
12. Bilyak, R. Methods of Obtaining Graphene. *Comput. Probl. Electr. Eng.* **2023**, *13*, 1–8. [CrossRef]
13. Lee, S.J.; Yoon, S.J.; Jeon, I.-Y. Graphene/Polymer Nanocomposites: Preparation, Mechanical Properties, and Application. *Polymers* **2022**, *14*, 4733. [CrossRef] [PubMed]
14. Verdejo, R.; Bernal, M.M.; Romasanta, L.J.; Lopez-Manchado, M.A. Graphene Filled Polymer Nanocomposites. *J. Mater. Chem.* **2011**, *21*, 3301. [CrossRef]
15. Geim, A.K.; MacDonald, A.H. Graphene: Exploring carbon flatland. *Phys. Today* **2007**, *60*, 35–41. [CrossRef]
16. Paton, K.R. Scalable production of large quantities of defect-free few-layer graphene by shear exfoliation in liquids. *Nat. Mater.* **2014**, *13*, 624–630. [CrossRef] [PubMed]
17. Hofmann, M.; Chiang, W.-Y.; Nguyễn, T.D.; Hsieh, Y.-P. Controlling the properties of graphene produced by electrochemical exfoliation. *Nanotechnology* **2015**, *26*, 335607. [CrossRef] [PubMed]
18. Lin, J.; Peng, Z.; Liu, Y.; Ruiz-Zepeda, F.; Ye, R.; Samuel, E.L.G.; Yacaman, M.J.; Yakobson, B.I.; Tour, J.M. Laser-induced porous graphene films from commercial polymers. *Nat. Commun.* **2014**, *5*, 5714. [CrossRef] [PubMed]
19. Tang, L.; Li, X.; Ji, R.; Teng, K.S.; Tai, G.; Ye, J.; Wei, C.; Lau, S.P. Bottom-up synthesis of large-scale graphene oxide nanosheets. *J. Mater. Chem.* **2012**, *22*, 5676. [CrossRef]
20. Bianco, G.V.; Losurdo, M.; Giangregorio, M.M.; Sacchetti, A.; Prete, P.; Lovergine, N.; Capezzuto, P.; Bruno, G. Direct epitaxial CVD synthesis of tungsten disulfide on epitaxial and CVD graphene. *RSC Adv.* **2015**, *5*, 98700–98708. [CrossRef]
21. Chee, W.K.; Lim, H.N.; Huang, N.M.; Harrison, I. Nanocomposites of Graphene/Polymers: A Review. *RSC Adv.* **2015**, *5*, 68014. [CrossRef]
22. González, F.J.; González-Castillo, E.I.; Peña, A.; Avalos Belmontes, F. *Nanofillers and Nanomaterials for Green Based Nanocomposites in Engineering Materials*; Belmontes, F.A., González, F.J., López-Manchado, M.A., Eds.; Springer International Publishing: Berlin/Heidelberg, Germany, 2023; pp. 13–30. ISBN 978-3-031-18428-4.
23. Sun, T.; Luo, W.; Luo, Y.; Wang, Y.; Zhou, S.; Liang, M.; Chen, Y.; Zou, H. Self-reinforced Polypropylene/Graphene composite with segregated structure to achieve balanced electrical and mechanical properties. *Ind. Eng. Chem. Res.* **2020**, *59*, 11206–11218. [CrossRef]
24. Bai, Q.-Q.; Wei, X.; Yang, J.-H.; Zhang, N.; Huang, T.; Wang, Y.; Zhou, Z.-W. Dispersion and network formation of graphene platelets in polystyrene composites and the resultant conductive properties. *Compos. Part A Appl. Sci. Manuf.* **2017**, *96*, 89. [CrossRef]
25. Tang, G.; Jiang, Z.-G.; Li, X.; Zhang, H.-B.; Dasari, A.; Yu, Z.-Z. Three-dimensional Graphene aerogels and their electrically conductive composites. *Carbon* **2014**, *77*, 592. [CrossRef]
26. Kim, C.I.; Oh, S.M.; Oh, K.M.; Gansukh, E.; Lee, H.-I. Graphenes for low percolation threshold in electroconductive nylon 6 composites. *Polym. Int.* **2013**, *63*, 1003. [CrossRef]
27. Vićentić, T.; Greco, I.; Iorio, C.S.; Miskovic, V.; Bajuk-Bogdanovic, D.; A Pašti, I.; Radulović, K.; Klenk, S.; Stimpel-Lindner, T.; Duesberg, G.S. Laser-induced graphene on cross-linked sodium alginate. *Nanotechnology* **2024**, *35*, 115103. [CrossRef]

28. Han, S.-J.; Garcia, A.V.; Oida, S.; Jenkins, K.A.; Haensch, W. Graphene radio frequency receiver integrated circuit. *Nat. Commun.* **2014**, *5*, 3086. [CrossRef]
29. Raimondo, M.; Naddeo, C.; Guadagno, L. Effect of non-covalent functionalization of graphene-based nanoparticles on the local electrical properties of epoxy nanocomposites. *IOP Conf. Ser. Mater. Sci. Eng.* **2021**, *1024*, 012004. [CrossRef]
30. Li, H.; Qu, Z.; Xie, Z.; Chen, Y. Field-induced semi-conductor-metal transition of hybrid ZnO and Graphene nanocomposites. *Comput. Mater. Sci.* **2022**, *203*, 111138. [CrossRef]
31. Li, Y.; Chen, P.; Chen, X.; Gong, H.; Hu, X.; Peng, Y.; Xu, X.; Xie, Z.; Xiu, X.; Chen, D.; et al. Gate-Controlled NiO/Graphene/4H-SiC Double Schottky Barrier Heterojunction Based on a Metal-Oxide-Semiconductor Structure for Dual-Mode and Wide Range Ultra-violet Detection. ACS Appl. *Electron. Mater.* **2022**, *4*, 1807. [CrossRef]
32. Orhan, E.O.; Efil, E.; Bayram, O.; Kaymak, N.; Berberoğlu, H.; Candemir, O.; Pavlov, I.; Ocak, S.B. 3D-Graphene-laser patterned p-type silicon Schottky diode. *Mater. Sci. Semicond. Process.* **2021**, *121*, 105454. [CrossRef]
33. Negri, E.; Fuscaldo, W.; Burghignoli, P.; Galli, A. Reconfigurable THz leaky-wave antennas based on innovative metal–graphene metasurfaces. *J. Phys. D Appl. Phys.* **2024**, *57*, 485102. [CrossRef]
34. Malik, S.; Zhao, Y.; He, Y.; Zhao, X.; Li, H.; Yi, W.; Occhipinti, L.G. Spray-lithography of hybrid graphene perovskite paper-based photodetectors for sustainable electronics. *Nanotechnology* **2024**, *35*, 325301. [CrossRef]
35. Kumar, P.; Šilhavík, M.; Červenka, J.; Kužel, P. Ultra-broadband THz absorbers based on 3D graphene. *J. Phys. D Appl. Phys.* **2023**, *56*, 505103. [CrossRef]
36. Rehman, M.A.; Roy, S.B.; Gwak, D.; Akhtar, I.; Nasir, N.; Kumar, S.; Khan, M.F.; Heo, K.; Chun, S.-H.; Seo, Y. Solar cells based on vertical Graphene nano hills directly grown on silicon. *Carbon* **2020**, *164*, 235. [CrossRef]
37. Zhao, J.; Ji, P.; Li, Y.; Li, R.; Zhang, K.; Tian, H.; Yu, K.; Bian, B.; Hao, L.; Xiao, X.; et al. Ultrahigh-mobility semiconducting epitaxial graphene on silicon carbide. *Nature* **2024**, *625*, 60. [CrossRef]
38. Kim, J.; Liu, Q.; Cui, T. Solution-gated nitrate sensitive field effect transistor with hybrid film: CVD Graphene/polymer selective membrane. *Org. Electron.* **2020**, *78*, 105551. [CrossRef]
39. Peplowski, A.; Janczak, D.; Wróblewski, G.; Słoma, M.; Górski, Ł.; Malinowska, E.; Pałko, T.; Jakubowska, M. Graphene electrodes for voltammetric measurements in biological fluids. *Circuit World* **2015**, *41*, 112. [CrossRef]
40. Novoselov, K.S.; Geim, A.K.; Morozov, S.V.; Jiang, D.; Zhang, Y.; Dubonos, S.V.; Grigorieva, I.V.; Firsov, A.A. Electric Field Effect in Atomic Thin Carbon Films. *Science* **2004**, *306*, 666. [CrossRef]
41. Elias; Alam, R.; Khatun, S.; Hossain, S.; Shah, S.S.; Aziz, A.; Uddin, N.; Hossain, M.A. Hydrothermal Synthesis of Carboxylated Functionalized Jute Stick Carbon and Reduced Graphene Oxide Based ZnO. Nanocomposite Photocatalysts: A Comparative Study. *J. Ind. Eng. Chem.* 2024; *in press*. [CrossRef]
42. Song, X.; Wang, X.; Wang, M.; Dong, W.; Li, M.; Yang, F. Solar Light-Responsive ZnS/Reduced Graphene Oxide Photocatalysts for Enhanced Hydrogen Evolution. *Catal. Lett.* **2024**, *154*, 2527. [CrossRef]
43. Lu, N.; Jing, X.; Zhang, J.; Zhang, P.; Qiao, Q.; Zhang, Z. Photo-Assisted Self-Assembly Synthesis of All 2D-Layered Heterojunction Photocatalysts with Long-Range Spatial Separation of Charge-Carriers toward Photocatalytic Redox Reactions. *Chem. Eng. J.* **2022**, *431*, 134001. [CrossRef]
44. Velasco-Hernández, A.; Esparza-Muñoz, R.A.; de Moure-Flores, F.J.; Santos-Cruz, J.; Mayén-Hernández, S.A. Synthesis and Characterization of Graphene Oxide—TiO_2 Thin Films by Sol-Gel for Photocatalytic Applications. *Mater. Sci. Semicond. Process.* **2020**, *114*, 105082. [CrossRef]
45. Ramalingam, G.; Perumal, N.; Priya, A.K.; Rajendran, S. A Review of Graphene-Based Semiconductors for Photocatalytic Degradation of Pollutants in Wastewater. *Chemosphere* **2022**, *300*, 134391. [CrossRef]
46. Oyedotun, K.O.; Mamba, B.B. Mamba New trends in supercapacitors applications. *Inorg. Chem. Commun.* **2024**, *170*, 113154. [CrossRef]
47. Luo, D.; Hu, X.; Ji, W. Construction of battery charge state prediction model for new energy electric vehicles. *Comput. Electr. Eng.* **2024**, *280*, 109561. [CrossRef]
48. Sankar, K.; Vijaya, R.; Selvan, K. Fabrication of flexible fiber supercapacitor using covalently grafted $CoFe_2O_4$/reduced graphene oxide/polyaniline and its electrochemical performances. *Electrochim. Acta* **2016**, *213*, 469. [CrossRef]
49. Liu, Z.; Wang, J.; Jia, X.; Li, W.; Zhang, Q.; Fan, L.; Ding, H.; Yang, H.; Yu, X.; Li, X.; et al. Graphene Armored with a Crystal Carbon Shell for Ultrahigh-Performance Potassium Ion Batteries and Aluminum Batteries. *ACS Nano* **2019**, *13*, 10631. [CrossRef]
50. Dai, J.; Cheng, C.; Li, H.; Cui, T.; Xiao, K.; Ning, J.; Liu, J.; Wang, C. Synthesis of nickel silicate/reduced graphene oxide composite for long-life lithium-ion storage. *Mater. Res. Express* **2023**, *10*, 035503. [CrossRef]
51. Polishchuk, Y.; Dubinevych, S.; Zinin, V.; Shembel, E. Graphene-enhanced sulfur cathode with high interface stability in Li-S batteries. *J. Phys. Conf. Ser.* **2022**, *2382*, 012005. [CrossRef]
52. Wu, Z.-Y.; Wu, C.-Y.; Duh, J.-G. Facile synthesis of boron-doped graphene-silicon conductive network composite from recycling silicon for lithium-ion batteries anodes materials. *Mater. Lett.* **2021**, *296*, 129875. [CrossRef]
53. Meng, W.-J.; Han, X.-Y.; Hou, Y.-L.; Xie, Y.; Zhang, J.; He, C.-J.; Zhao, D.-L. Defect-repaired reduced Graphene oxide caging silicon nanoparticles for lithium-ion anodes with enhanced reversible capacity and cyclic performance. *Electrochim. Acta* **2021**, *382*, 138271. [CrossRef]
54. Cho, Y.; Kim, J.M.; Yan, B.; Hong, H.; Piao, Y. Influence of flake size and porosity of activated graphene on the performance of silicon/activated graphene composites as lithium-ion battery anodes. *J. Electroanal. Chem.* **2020**, *876*, 114475. [CrossRef]

55. Argyropoulos, D.-P.; Selinis, P.; Vrithias, N.R.; Viskadourakis, Z.; Salmas, C.E.; Karakassides, M.A.; Kenanakis, G.; Elmasides, C.; Farmakis, F. Poly-Lactic Acid/Graphene Anode for Lithium-Ion Batteries Manufactured with a Facile Hot—Pressed Solvent-Free Process. *J. Electrochem. Soc.* **2023**, *170*, 050515. [CrossRef]
56. Černevičs, K.; Yazyev, O.V. From defect to effect: Controlling electronic transport in chevron graphene. *Electron. Struct.* **2023**, *5*, 014006. [CrossRef]
57. Chen, B.; Wang, D.; Zhang, B.; Zhong, X.; Liu, Y.; Sheng, I.; Zhang, Q.; Zou, X.; Zhou, G.; Cheng, H.-M. Engineering the Active Sites of Graphene Catalyst: From CO_2 Activation to Activate $LiCO_2$ Batteries. *ACS Nano* **2021**, *15*, 9841. [CrossRef]
58. Yanik, M.O.; Yigit, E.A.; Akansu, Y.E.; Sahmetlioglu, E. Magnetic conductive polymer-graphene nanocomposites-based supercapacitors for energy storage. *Energy* **2023**, *138*, 883–889. [CrossRef]
59. Bin, Y.; Zhang, J.; Kou, T.; Song, Y.; Liu, T.; Li, Y. Paper-Based Electrodes for Flexible Energy Storage Devices. *Adv. Sci.* **2017**, *4*, 1700107. [CrossRef]
60. Wang, Z.; Li, Q. Contractile and torsional dual-responsive artificial muscles actuated by electric heating and water droplet. *Smart Mater. Struct.* **2023**, *32*, 075017. [CrossRef]
61. Helps, T.; Taghavi, M.; Rossiter, J. Thermoplastic electroactive gels for 3D-printable artificial muscles. *Smart Mater. Struct.* **2019**, *28*, 085001. [CrossRef]
62. Gao, Y.; Wang, X.; Fan, C. Advances in graphene-based 2D materials, for tendon, nerve, bone/cartilage regeneration and biomedicine. *iScience* **2024**, *27*, 110214. [CrossRef]
63. Park, C.-L.; Goh, B.; Kim, K.J.; Oh, S.; Suh, D.; Song, Y.-C.; Kim, H.; Kim, E.S.; Lee, H.; Lee, D.W.; et al. Synergistic actuation performance of artificial fern muscle with a double nanocarbon structure. *Mater. Today Adv.* **2024**, *21*, 100459. [CrossRef]
64. Mahmoudifard, M.; Soleimani, M.; Hatamie, S.; Zamanlui, S.; Ranjbarvan, P.; Vossoughi, M.; Hosseinzadeh, S. The different fate of satellite cells on conductive composite electrospun nanofibers with graphene and graphene oxide nanosheets. *Biomed. Mater.* **2016**, *11*, 025006. [CrossRef] [PubMed]
65. Romo-Rico, J.; Bright, R.; Krishna, S.M.; Vasilev, K.; Golledge, J.; Jacob, M.V. Antimicrobial graphene-based coatings for biomedical implant applications. *Carbon Trends* **2023**, *12*, 100282. [CrossRef]
66. Ma, Z. Advances in graphene-assisted flexible substrate sensors for human motion monitoring. *Int. J. Electrochem. Sci.* **2024**, *19*, 100760. [CrossRef]
67. Butler, D.J.; Sankhe, C.S.; Khamsi, P.S.; Gomez, E.W.; Ebrahimi, A. Solution-processed graphene films for electrochemical monitoring of extracellular nitric oxide released by breast cancer cells. *2D Materials* **2023**, *11*, 015021. [CrossRef]
68. Wekalao, J.; Patel, S.K.; Anushkannan, N.; Alsalman, O.; Surve, J.; Parmar, J. Design of ring and cross shaped graphene metasurface sensor for efficient detection of malaria and 2 bit encodng applications. *Diam. Relat. Mater.* **2023**, *139*, 110401. [CrossRef]
69. Islam, M.S.; Branigan, A.; Ye, D.; Collinson, M.M. Reduced Graphene Oxide Decorated Titanium Nitride Nanorod Array Electrodes for Electrochemical Applications. *Electrochem* **2024**, *5*, 274–286. [CrossRef]
70. Oktay, B.; Erarslan, A.; Üstündağ, C.B.; Özerol, E.A. Preparation and characterization of graphene oxide quantum dots/silver nanoparticles and investigation of their antibacterial effects. *Mater. Res. Express* **2024**, *11*, 015603. [CrossRef]
71. Jing, Z.; Zhang, Q.; Cheng, Y.; Ji, C.; Zhao, D.; Liu, Y.; Jia, W.; Pan, S.; Sang, S. Highly sensitive, reliable, and flexible piezo-resistive pressure sensors based on graphene-PDMS @ sponge. *J. Micromech. Microeng.* **2020**, *30*, 085012. [CrossRef]
72. Karaca, E.; Acaralı, N. Application of graphene and its derivatives in medicine: A review. *Mater. Today Commun.* **2023**, *37*, 107054. [CrossRef]
73. Priyadarsini, S.; Mohanty, S.; Mukherjee, S.; Basu, S.; Mishra, M. Graphene and graphene oxide as nanomaterials for medicine and biology application. *J. Nanostruct. Chem.* **2018**, *8*, 123. [CrossRef]
74. Han, S.; Sun, J.; He, S.; Tang, M.; Chai, R. The application of graphene-based biomaterials in biomedicine. *Am. J. Transl. Res.* **2019**, *11*, 3246. [PubMed]
75. Nicoletti, N.F.; Marinowic, D.R.; Perondi, D.; Gonçalves, J.I.B.; Piazza, D.; da Costa, J.C.; Falavigna, A. Non-Cytotoxic Graphene Nanoplatelets Upregulate Cell Proliferation and Self-Renewal Genes of Mesenchymal Stem Cells. *Int. J. Mol. Sci.* **2024**, *25*, 9817. [CrossRef] [PubMed]