Graphene-Based Nanomaterials

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Abstract Graphene, the wonder carbon-material is a lone-atom-wide two-dimensional nanostructure having large surface area of modifiable interest for fabricate composites. Graphene-based nanostructure has fascinated enthusiasm among research groups for its exclusive physico-chemical properties and utilization in numerous fields such as energy-storage devices, fuel cells, bioengineering, sensors, and analysis. Graphene nanomaterials with various utilizations are estimated to transform many other fields like optical, electronic, thermo-, and mechanic. During hybridization, these nanomaterials are usually treated with chemicals for functionalization and material reduction, together doping with foreign atoms, oxidation, which introduce functional groups. A number of techniques have been followed for developing graphene nanomaterials (both “top down” and “bottom up”) having its unique advantages and disadvantages. This book chapter will lay down the prospects and consequences of new progress graphene nanoparticles, manufacturing processes, challenges, and its potential value-added applications in assorted fields.

Keywords Graphene nanomaterials · Top down · Bottom up · Utilization · Value-added applications · Challenges

1 Introduction

Till now (2022), there are almost as many patent applications as there are scholarly articles published each year about graphene, its properties, and applications. Since the carbon allotrope in graphite contains a lot of double bonds, the name is derived from “graphite” and the suffix -ene [1]. The term “graphene” was first used in 1986 by the chemists Hanns-Peter Boehm, Ralph Setton, and Eberhard Stump. The compounds graphite and -ene, which stands for polycyclic aromatic hydrocarbons, are combined

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to form this term [1–3]. Researchers continually discover and develop new, superior materials in every field of engineering, pharmacology, biotechnology, etc., leading to believe that graphene is the substance of the future for all of the aforementioned fields. In 2004, Andre Geim and Konstantin Novoselov made initial discovery of graphene. The layers of 2D graphene that make up 3D graphite are confined collectively with substantially weaker Van der Waals bonds rather than by molecular bonds [1–5]. The graphene layers have a weak connection that allows them to slide over one another easily, giving the material appropriate to be utilized as a lubricant because it has a soft and slippery feel. Geim and Novoselov separated monolayer graphene sheets for the first time off the plane of an extremely aligned pyrolytic graphite flake in 2003 using several peels of ordinary adhesive tape.

A plane sheet of carbon atoms only single atom wide makes up the two-dimensional allotrope of carbon known as graphene (G). One atom acts as the vertex of each hexagon in the hexagonal, honeycomb lattice that holds these atoms together and resembles "chicken wire". Out of six electrons, two and four electrons are arranged in inner and valence shells. Every electron has confined with another three electrons via extremely tough covalent bonds which are really hard to split, the last electron of outer shell accessible for conduction or relate with other atoms or molecules [2, 3]. Both sides of graphene layer have p-orbitals and "pi" electrons, also referred to as the highly mobile electrons. The overlap of the pi orbitals in graphene strengthens carbon-to-carbon bonds. The bonding of these orbitals controls the electric characteristics of graphene. This 2D carbon graphene lattice is often found as platelets or flakes that are around 0.3 nm thick [3]. Although it is typically thinner than this, the layer can stretch up to roughly 0.5 mm in the lateral direction.

Through an extremely crystalline arrangement and exceptional, distinctive physical properties, monolayer graphene is produced via this so-called mechanical exfoliation technique [3, 5]. They transferred the graphene layers from the graphite to thin silicon dioxide (SiO_2) on a silicon wafer using either the scotch tape method or micromechanical cleavage. SiO_2 provided almost charge-neutral graphene layers by electrically isolating it from the graphene and barely interacting with it. Serving as a "back gate" electrode, the silicon underlying the SiO_2 might be utilized to change the charge density in the graphene across a wide range.

Recently, there is a significant increase in attention for graphene-based nanomaterials for use in nanocomposites, energy-storage systems, electronics, chemical sensors, opto-electronics, and health applications including osteogenic [1, 4, 6]. Applications for graphene include energy-storage devices like supercapacitors and lithium-ion batteries, conducting electrodes, and gas detection. The internal structure of graphene is, each atom in a graphene sheet forms a strong bond with its three closest neighbors, adding one electron to the sheet's overall valence band. The key advantages of graphene include its near-perfect heat and electrical conductivity, lightness, strength, thinness, and other properties. The use of graphene in a composite precludes the production of additional nano-sized active materials, improves non-Faradic capacitive behavior, boosts conductivity, and stops disintegration. Numerous extraordinary electronic features of graphene have fascinated a lot of interest, including Dirac energy dispersion, relativistic effects, the half-integer quantum Hall effect, and Klein tunneling. Additionally, in its Van der Waals heterostructures with other two-dimensional materials, it hosts a number of single particle and emergent correlated states that are topologically non-trivial [5–8].

2 Physico-Chemical Properties of Graphene Nanomaterials

After the year 2004, it was established that 2D complex can subsist due to monolayer graphene which was isolated. However, the scientists were looking for more details about it. After suspended graphene layers were analyzed by high-resolution transmission electron microscopy (TEM), researchers considered that can be established the cause to be minor rippling in graphene, altering arrangement of layers. Though, by lately they suggested that the carbon-to-carbon bonds in graphene are very tiny and robust that they resist thermal disturbance from unsettling it.

2.1 Electronic Properties

Conjugating both holes and electrons as charge carriers, zero-overlap semi-metal graphene is established as highly electrical conductor. Then, 2, 4 electrons are arranged in inner and outer shells, respectively, in graphene. Out of four valence electrons, three electrons are bonded to other atoms to form 2D plane, whereas one electron is always free for electronic conduction [9]. Those strongly mobile electrons ("pi" electrons) are occupying below and above the graphene layer. The overlapped pi orbital increases the strength of carbon–carbon bonds. Basically, the valence and conduction bands or bonding and anti-bonding of "pi" orbital of graphene are termed as electronic properties.

Over through last decade, it was studied that electrons and holes have zero effective mass at the Dirac point in graphene. This happens due to the spectrum for excitations or energy-movement association, which behaves linear for less energy beside the six separate bends of Brillouin zone. The electrons and holes are termed as Dirac fermions, and six turns of the Brillouin zone are called as Dirac points [10]. Electric conduction is actually very low because of zero-density status at Dirac points. Although Fermi level can be adjusted with doping holes or electrons for material, electronic conductivity can be improved by that.

Graphene has extremely high electron mobility of more than 15,000 $\mathrm{cm}^2\ \mathrm{V}^{-1}\ \mathrm{s}^{-1}$ and tentative potential of 200,000 $\mathrm{cm}^2\ \mathrm{V}^{-1}\ \mathrm{s}^{-1}$ [11]. Due to lack of mass, the electrons behave alike of photons during their mobility. Those charge carrier electrons are capable to move sub-micrometer path with no spreading, a trend called as ballistic transport [11]. Although the limiting factor may be the substrate or the quality of graphene. As an example, the substrate silicon dioxide has the mobility of 40,000 $\mathrm{cm}^2\ \mathrm{V}^{-1}\ \mathrm{s}^{-1}$.

2.2 Mechanical Strength

Graphenes' prominent physical property is its intrinsic strength (ultimate tensile strength 130 GPa) because of 0.142 Nm extended carbon bonds, which made graphene as the strongest material ever explored [12]. Compared to strength, graphene is also very light in weight (0.77 mg/m^2) [12]. It is frequently mentioned that a solitary layer of graphene (simply one atomic wide) is adequate in dimension that can cover a complete football ground and would weigh less than one gram.

As elastic property, graphene is capable to preserve its own shape and size after strain, which makes it special. Atomic force microscope (AFM) analysis of graphene was conducted in 2007, where graphene layers were suspended over silicone dioxide cavities. Those results provided that between 2 and 8 Nm thick of graphene layer had spring constants in the range of 1–5 N/m and a Young's modulus (unlike 3D graphite) of 0.5 TPa [15]. Those exceptional results were based on theoretical prediction assuming graphene as flawless containing no deficiency and therefore costly and tricky to synthetically reproduce, although manufacturing processes are gradually improving, ultimately reducing expenses and difficulty [13].

2.3 Optical Properties

Graphene has the capacity to absorb around 2.3% of white light, which is an exceptional and attractive property, particularly taking into account that it is merely lone atomic wide. Owing to its aforesaid electronic properties, the electrons act like massless charge carriers with extremely high mobility [14]. The amount of white light absorbed depends on the fine structure constant, rather than being dictated by material specifics. Addition of one more sheet of graphene enhances the quantity of white light absorbed by roughly similar value (2.3%). Graphenes' opacity of $\pi\alpha \approx 2.3\%$ connects to a universal dynamic conductivity value of $G = e^{2/4}\ \hbar$ (± 2–3%) more than the noticeable frequency series [14].

The following characteristics apply to this amazing nanomaterial:

- Owing to its dense arrangement and tough covalent bonds among atoms, graphene is 200 times stronger than steel while also being exceedingly light.
- Really thin but incredibly durable.
- Flexible; it can be folded or bent.
- Due to its small structure, it can function as a perfect barrier. Helium cannot even get through it.
- Because of its little thickness, transparent, graphene is practically invisible since it only absorbs 2.3% of the light that passes through it.
- Tiniest substance presently known to exist.
- Chemically inactive.
- Conduction band does not have any band gap due to fourth electron, the pi-electron and the valence shell are not normally elevated toward an upper plane.

- Because of the highly mobile free pi-electrons, more conductive than copper both electrically and thermally.
- While carbon is the fourth large prevalent component on earth, graphene is honestly affordable.
- Flexibility alters the resistance of the sheet and able to be extended up to 20% without causing faults.
- Researchers from the University of Maryland and the Lawrence Berkeley National Laboratory have also noted that the flexibility pattern of graphene layer could change the magnetic characteristics. Corresponding result in pi-electrons moving in rounds in graphene layer, like a tough magnetic field, had been applied perpendicular to the sheet even though there was no actual external magnetic field (up to 300 T or 107 times the earth's magnetic field). This might make it possible to manipulate the conductivity, optical, and microwave properties of graphene. Currently, any alternative feasible is not available to produce magnetic fields of that size.
- Another peculiar behavior that was noticed in two-dimensional graphene structures under strong magnetic fields and low temperatures is the quantum Hall effect. This is a quantum–mechanical interpretation of the Hall effect, in which electrons enter quantized energy levels and the Hall conductance undergoes quantum Hall transitions to take on quantized values.
- By using doping or other techniques, graphene can be given semiconducting features, such as an adjustable band gap, even if the lack of a band gap prevents graphene conduction from being switched off like a transistor.
- Graphene oxide (GO) is graphene derivatives whose large array of physicochemical properties is modified and used for specific utilizations.

3 Synthesis of Graphene Nanomaterials

A number of techniques, including ball milling, exfoliation, chemical vapor deposition, and physical vapor deposition, can be used to create graphene nanomaterials. Several techniques for the exfoliation of graphite have been documented as a result of the long-standing interest in graphene and the numerous researchers that have been working on its creation. They fall into two categories like top-down strategy and the bottom-up strategy.

Processes of synthesizing graphene depend on preferred purity, size, and efflorescence. Many techniques for producing thin graphitic films have been discovered at the early stage. In the late 1970s, carbon precipitated as thin graphitic coatings on the surfaces of transition metals [15]. In 1975, few-layer graphite was produced using chemical breakdown procedures on a single platinum crystal, but owing to lack of characterization tools or possibly because of its restricted prospective uses, this material was not recognized as graphene.

Their electronic properties were not investigated at that time since it was difficult to isolate and transfer on resisting supports. At the end of nineteenth century, Ruoff and associates sought to separate fine graphitic flakes on silicon dioxide support using mechanically friction decorative islands on extremely organized pyrolytic graphite [16]. On the characterization of their electrical properties, there was, however, no information. Later, in 2005, Kim and associates used a similar procedure to do this, and the electrical properties were published [17]. However, graphene research proceeded quite swiftly when Geim and others declared their effort of separating graphene over silicon dioxide support, analyzing all electrical properties. Following the material's discovery, numerous methods were discovered to manufacture slim graphitic layers and few sheets of graphene. Thin graphene flakes exfoliation from their bulk counterparts and additional substances including molybdenum disulphide, niobium diselenide, and boron nitride led to the primary experimental demonstration of two-dimensional crystals in 2004 and 2005. However, graphite was first mechanically exfoliated with scotch tape to produce tiny flakes of a few microns, which were then used to make graphene [17]. Although the graphene produced by this procedure is of the highest quality, mass manufacturing of graphene requires a fabrication technique that can manufacture wafer-scale graphene.

A wide range of techniques has recently been discovered for the manufacturing of graphene. But currently, mechanical cleaving, chemical exfoliation, chemical synthesis, and thermal chemical vapor deposition synthesis are the methods most often used. Other techniques, such as producing microwaves and unzipping nanotubes, have also been reported [18]. Although it was shown that mechanical exfoliation using an atomic force microscopy cantilever could manufacture graphene with a few layers, the method was constrained by the graphene's thickness, which ranged to 10 nm, or roughly equivalent to 30-layer graphene.

Chemical exfoliation of solution dispersed graphite is accomplished by injecting large alkali ions between the graphite layers. Creating graphite oxide, spreading it in a solution, and then reducing it using hydrazine are similar processes. Chemical synthesis is the term for this. The most crucial process for producing graphene on a big scale, much like carbon nanotubes, has shown to be catalytic thermal chemical vapor deposition. The phrase "thermal chemical vapor deposition" refers to the thermal chemical vapor deposition procedure that makes use of a resistive heating furnace. The term for the thermal chemical vapor deposition method that makes use of plasma-assisted growth is plasma-enhanced chemical vapor deposition. Every aspect of our environment has drawbacks, so the final application of graphene will determine which synthesis method is best. As an example, the mechanical exfoliation technique can produce monolayer to few-layer graphene, but there is little chance of successfully producing a structure similar to that structure.

Additionally, chemical synthesis techniques are less-range temperature methods, by which it is possible graphene synthesis at room temperature on a range of substrate types, particularly polymeric ones. However, the large-area synthetic graphene produced by this technique is scattered and not homogeneous. Again, depending on the degree of reduction, the partial decrease of graphite oxide which effect from creation of graphene from reduced graphene oxides usually deteriorates the electrical properties of graphite oxide over time. Contrarily, by substituting Si, thermal chemical vapor deposition technique is most suited in favor of creating bigger-space devices that are helpful for upcoming corresponding metal oxide semiconductor skill [19]. Another technique to generate graphene is by thermally graphitizing a silicon carbide surface; however, this method has two drawbacks: a high process temperature, and it cannot be transferred to other substrates. The unique feature of the thermal chemical vapor deposition technique is its capacity to deposit a uniform layer of carbon atoms that have been chemically and thermally catalyzed onto metal surfaces.

3.1 Top-Down Technique

Graphene or modified graphene sheets are produced using a top-down technique by exfoliating or separating graphite and its derived including graphite fluoride and graphite oxide.

Chemical Exfoliation

Chemical synthesis represents the finest ways to make graphene. Modifying graphite and a graphite intercalation component chemically to create colloidal suspension, this is then converted into graphene. Numerous paper-like materials, polymer composites, energy-storage materials, and transparent conductive electrodes have already incorporated graphene produced chemically into them. The Brodie, Hummers, and Staudenmaier processes were first used to create graphene oxide in 1860 [23].

Chemical exfoliation is a two-continued method. By initial lowering the Van der Waals forces between two layers, one can enhance the interlayer separation. Consequently, it produces chemicals that intercalate graphene. Then, a single sheet or a few layers of graphene are exfoliated using rapid heating or sonication. To produce various layer thicknesses for single-layer graphene oxide, density gradient ultracentrifugation is combined with ultrasonication. It is simple to create graphene oxide using the Hummers process, which includes oxidizing graphite with strong oxidizing chemicals like potassium permanganate and sodium nitrate in sulfuric acid/phosphoric acid. In a dimethyl formide/water combination, single-layer graphene was produced via ultrasonication. As a result, interlayer spacing rises from 3.7 to 9.5 A. High functional group densities call for oxidation, and graphene-like properties call for reduction. The sheets are spread by chemically reducing single-layer graphene sheets with hydrazine monohydrate. Polycyclic aromatic hydrocarbons have been used in the production of graphene using a cyclodehydrogenated and planarized dendrict precursor. Make a couple small graphene domains. Larger flakes of poly-dispersed, hyper-branched polyphenylene are produced by the precursor. The initial ones were produced through oxidative cyclodehydrogenation and $FeCl_3$. Graphene is dispersed using orthodichlorobenzene, perfluorinated aromatic, chloroform, isopropanol solvents. An electrostatic force draws graphene on silicon dioxide substrates to the Si substrate. Reduced graphene oxide is first-class graphene obtained via exfoliation by heating or reduction of graphite oxide.

3.2 Bottom-Up Techniques

The typical graphene dimensions as well as its layers depth are generated through various bottom-up techniques, and perks and drawbacks of every technique will be discussed.

Mechanical Exfoliation

The much more typical and important method for producing single-layered graphene flakes on chosen substrates may be mechanical exfoliation. It is the initial known technique for producing graphene. This top-down nanotechnology method stresses the materials that make up the layered structure's surface longitudinally or transversely. Weak Van der Waals forces allow mono-atomic graphene sheets as stack one on top of the other to create graphite. The space and bond energy between sheets are 3.34 A and 2 eV/nm^2, respectively. To split mechanically single atomic sheet from graphite, ~ 300 N/mm^2 external force is needed [20]. In graphite, stacking of sheets is caused by the crossover of a half-filled p-orbital that is orthogonal toward the sheet's plane and involves Van der Waals forces. Exfoliation means inverse from assembling together since there is weaker bonding and a larger average crystallite size in the direction parallel than there is in the hexagonal lattice plane and vice versa. In fact, layers of graphitic materials like highly ordered pyrolytic graphite, single-crystal graphite, or natural graphite can be peeled off to produce graphene sheets of various thicknesses. The many tools that can be employed to carry out this peeling or exfoliation include Scotch tape, ultrasonication, electric fields, transfer printing methods, etc. The highly oriented pyrolytic graphite has occasionally been connected to the substrate using traditional adhesives like epoxy resin or even S-adenosyl methionine for advancing the production of individual or more layers graphene sheets.

A latest research reveals the use of gold films to manufacture macroscopic graphene patterns from patterned highly oriented pyrolytic graphite. The typical methods used to characterize graphene flakes that are made using mechanical exfoliation processes include optical microscopy, Raman spectroscopy, and atomic force microscopy. An atomic force microscopy analysis is performed for exfoliated graphene to measure the width and amount of sheets. There is low chance of finding a single-layer flake, and this technique produces poorer yields for mono- and several sheets of graphene with smaller flakes. Optical microscopy is a conventional way for discovering single-sheet graphene. Graphene peels above the surface offer a significant color contrast in respect to thickness. The silicon dioxide layer on silicon wafers is 300 nm thick and produced thermally [21]. This is one of the fastest, finest specific processes for gauging crystallinity and width of graphene sheets. This is because, depending on the number of sheets present, graphene exhibits various Raman spectra. For micromechanical process, graphene is peeled off single graphite crystal via sticky ribbon. Flaking off graphite leaves multilayer graphene above ribbon. Through frequent flaking, multi-sheet graphene is divided within countless sheets of some-layer graphene.

In order to remove, ribbon is then secured onto acetone support. Unopened ribbon is used for the final peeling. With diameters in support of mono-sheet graphene (wafer spanning) from nanometers to many tens of micrometers, the generated flakes have a wide range in size and thickness. Absorption speed of monolayer graphene is approximately 2%, yet due to interference effects, it can still be seen under a light microscope on silicon dioxide/silicon [22]. Despite the fact that this procedure poses very few challenges, it is labor-intensive to locate the graphene flakes on the substrate surface. The prepared graphene is of extremely high quality and has almost no defects. Mechanical exfoliation still requires improvement based on industrial-scale, flaw-free, more-purity graphene wholesome manufacturing for area of nanotech.

Pyrolysis of Graphene

Using the solvothermal process, graphene was chemically created in a bottom-up manner. During this heat reaction, salt and ethanol were mixed in a closed vessel at a 1:1 molar ratio. Sheets of graphene can be smoothly separated by pyrolyzing sodium ethoxide with sonication. Up to 10 nm thick graphene sheets were produced as a result. In order to look at crystalline arrangement, various layers, graphitic character, and band configuration, three different techniques have been used: selected area of electron diffraction, transmission electron microscopy, and Raman spectroscopy [24]. Raman spectroscopy of graphene layers indicated large D-band and G-band, and an intensity ratio of I_G/I_D was 1.16, which is suggestive of flawed graphene. This technique had the benefit of producing highly pure, functionalized graphene with ease at low temperatures.

4 Functionalization of Graphene

Low-cost graphene functionalizations by conventional ways are well known. By changing exterior-plane chemistry of graphene oxide for modification of its properties in a variety of ways, such as by replacing the oxygen atoms through other atoms/molecules or by connecting molecules to oxygen atom for generate variants known as nanocomposite materials. This can be possible because graphene oxide has an abundance of oxygen-containing groups. Functionalization is a key chemical process that significantly affects the material's reactivity and enables the addition of new functions, features, capabilities, or attributes [25]. This customization of graphene has been used in support of specific purposes like biosensors, drug delivery, catalysts, semiconductors, or for improving material characteristics of complex supplies. Both covalent and non-covalent bonds can be used to combine the exclusive properties of *G* and graphene oxide amid different molecules and nanomaterials, like metals, metal oxides, magnetic nanoparticles, and quantum dots (extremely tiny semiconductor elements along special characteristics), to permit all variety of utilizations.

4.1 Immobilization

In order to immobilize molecules like enzymes on graphene support structures, bonding is also used to attach the molecules to the supports. In medication delivery applications, the graphene serves as a carrier for the enzymes, which serve as catalysts for biochemical reactions [26]. Because of their immobilization, the enzymes are less susceptible to environmental influences, they are more stable and do not readily mix with the surroundings, and they can therefore be reused while still maintaining their integrity and effectiveness.

4.2 Covalent Bonding

When employed for attaching location for covalent interactions along various molecules and nanoparticles, the oxygen-containing functional groups on the GO lattice's surface or along the margins of the GO sheets can change the surface functionality and enable a range of functions [27]. Thus, graphene is a potential first step in the immobilization of numerous substances, such as a variety of metals, proteins, fluorescent compounds, medications, and inorganic nanoparticles. However, by accommodating the extra molecules, covalent functionalization can damage the structure of *G* lattices, leading to flaws and the deterioration of the lattice's electrical characteristics.

4.3 Non-covalent Bonding

The non-covalent functionalizations for graphene or graphene oxide are made possible by the reduced Van der Waals and electrostatic forces or interactions between graphene and desired element [28]. The structure or electrical properties of the graphene lattice are unaffected even while additional chemical groups are simultaneously added to facade. Non-covalent functionalization could improve graphene's dispersion ability, biocompatibility, reactivity, binding power, and sensing effects.

Van der Waals forces often govern bonds between G and organic molecules. Pure G cannot form ionic connections because it lacks oxygen atoms, which are necessary for such interactions [28]. However, GO derivatives are capable of ionic interactions, and hydrogen bonding due to GO's edges and surface both has oxygen groups.

Non-covalent pi–pi bonds are created when two overlapping regions of atomic orbitals come into contact with one another. In addition, aromatic hexagonal rings, which contain one free electron each and are cyclic atomic structures, interact with molecules via molecular pi–pi interactions. Such rings are frequently found in organic compounds and polymers, and graphene also possesses a ring structure. However, the unbound electrons would tend to resist one another if the hexagonal nucleus was in direct opposition or parallel to one another, lowering the strength of the bond and lessening the impact of non-covalent contact among aromatic rings [28]. However, distance between electrons of two layers that are straight across from one another is less negative than the distance between the atoms composing an individual ring's periphery rings that are equalized across one another via short path among closest peripheral atoms that make up the nucleus that will have a stronger non-covalent pi–pi interaction. The electrons will instead fall into the somewhat fewer negative areas on each face of opposing couples of atom as a result, preventing them from being in direct opposition to one another. Electromagnetic interactions work inside or between molecules rather than the sharing of electrons. The same interactions still take place even if the rings are in ordered differently, like perpendicular with one another in a T-formed arrangement.

Any metal, an anion, a different particle, or yet other system can interact with an electron-rich system like graphene. Biological relationships depend on non-covalent interactions across systems, featuring the stacking of DNA's and RNA's double-ringed nucleotides [29]. Non-covalent bonding has the significant advantage that, in the majority of appliances, graphene and graphene oxide pattern are not interrupted, preserving critical characteristics like electrical conductivity, mechanical strength, and solubility. The many "-" contacts among graphene-derived polymers, for instance, polymers with duplicating aromatic rings, can tightly bind monolayers in bigger or extended systems, producing very uniform polymer compounds with improved mechanical, electrical, and thermal properties. GO has specific promise for usage in nano-medicine, as do several other functional groups that enable further surface functionalization and improve biocompatibility [30].

4.4 Graphene Conjugation with Organic Molecules

Through the processes of amination, esterification, and halogenation, organic compounds could be utilized for covalently or non-covalently functionalized graphene arrangement. In studies on covalent functionalization methods for graphene quantum dots, the graphene plane was functionalized with organic compounds, for example, alcohols and diamines for bioimaging applications [29]. It demonstrates that graphene and the two dipoles (T, P) have fewer interactions compared to non-ionic particles.

4.5 Graphene Functionalization with Polymers

Graphene and GO can be functionalized with a variety of polymers through chemical and non-covalent interactions. The created nanoparticles can be used in catalysis, medicine, and power generation [30]. Researchers proved that it is feasible to covalently functionalize GO with polyvinyl alcohol (PVA) in order to enhance PVA's physical merits. Compared to non-modified PVA, the authors found a 400% increase in mechanical parameters and a 60% rise in Young's modulus. It is known that adding GO to PVC increases contact angle values, hence reducing surface roughness.

4.6 Graphene Establishment in Anti-cancer Drugs

The non-covalent interactions between drug and graphene layer allowed for the combination of graphene-based nanomaterial (GBN) by anti-cancer treatments. As reported by scientists, covalent functionalization of graphene oxide along sulfonic acid groups and folic acid enhanced its selectivity for MCF7 cells (human breast cancer cell line) [31]. The incorporation of anti-cancer drugs through non-covalent alteration significantly boosts therapeutic effectiveness in comparison with separate medications. The covalent alteration of graphene oxide along chlorotoxin (CTX) increases the release of medication to glioma cells.

4.7 Graphene Alteration with Biomolecules

Chain-length proteins, catalysts, and polymers all have graphene and GO bonded to them either covalently or non-covalently. The substance could be used to build detectors that are extremely sensitive to small molecules like antigens [32]. In order to act as a cationic vector for gene transport, GO may be chemically linked with poly-ethyleneimine, according to research. The compound was used as a bioimaging material because of its potent photoluminescence properties.

The scientists achieved covalent and non-covalent conjugation of GBN with biomolecules such as enzymes, sugars, and pathogens for a number of pharmaceutical uses, cancer treatment, synthetic biology, bioimaging, and the advancement of biomaterials in order to identify extremely small portion of biological molecules such as nucleic acids, peptides, or proteins, particularly for disease detection. The usage of GBN as nano-modifiers has received considerable attention in scholarly papers [31, 32]. Data on the nature of the produced nanomaterial are similarly scarce. The lack of knowledge about GBN's biosynthetic pathways for biomedical applications is another disadvantage. However, this study would open the door for later applications.

5 Advantages and Disadvantages of Graphene Synthesis Methods

5.1 *Advantages*

- The exfoliation process produces graphene that is extremely pure and of high grade. The exfoliation method's simplicity and lack of complexity make it ideal for laboratory testing. The size of the getting flakes and their controllability are bad for industrial formation [33].
- If we allow graphene to expand on layers, it will have great controllability and a low infinity size of its layers that can pass more. Due to the low clarity of the material obtained, these procedures are not appropriate for laboratory analyses of graphene [33].
- The structure is not only harmed when we compare the electrochemical approach with the reduction of oxidized graphene into graphene oxide, but the material also exhibits strong electrical conductivity without incurring any loss in the treatment. Compared to alternative chemical exfoliation methods like liquid-phase exfoliation of graphite by substantial intercalation and expansion of graphene, the electrochemical technique produces sheets of graphene that are more robust, clean, and huge in size [34].
- To create a liquid-phase solution, the prepared sheet of graphene can be dispersed in an organic solvent. At 150 °C, an organic solvent like dimethyl formamide (DMF) can evaporate.

5.2 *Disadvantages*

- The output from the liquid exfoliation process was decreased.
- The newly produced graphene has some structural and manufacturing flaws. Thus, it is impossible to guarantee the quality of newly produced graphene.
- The contaminants in different types of unclean salt may be fixed between layers of graphene in the electrochemical procedure, which has an impact on the physical phenomena of graphene [33].
- Additionally, because the thickness parameter is managed by the chemical vapor deposition (CVD) process, one cannot control it [34].
- To allow for a comprehensive benchmark of this material and an analysis of its prospective performance, a deeper understanding of factors including breakdown voltage, electron rate, and corresponding saturation current is necessary.

6 Applications of Graphene Nanomaterials

6.1 Graphene in Fuel Cells

Graphene is impermeable to even hydrogen atoms, which are thought to be the tiniest atoms. In a different study, Sir Andre Geim and his group investigated the possibility of graphene's ability to block protons. Surprisingly, protons may move across graphene. The characteristic definitely increases fuel cell results by minimizing fuel transfer, and this issue significantly decreases fuel cell lifetime and efficiency. Fuel cell is a power generation device that converts the chemical energy of hydrogen and oxygen directly into electricity and can achieve an efficiency of more than 50% [35].

6.2 Graphene Batteries

Since graphene-reinforced lithium-ion batteries have amazing qualities including increased flexibility and weight, longer life, higher capacity, and quicker charging times, they could be employed in portable electronics.

Graphene lithium-ion batteries are anticipated to be developed within the next one to three years, solid-state batteries over the next four to eight years, and graphene supercapacitors within the next ten years. Lithium-ion batteries may eventually be replaced with graphene sodium-ion and graphene aluminum-ion batteries because they are less expensive, easier to recycle, and more prevalent in nature than lithium.

Future electric vehicles may use graphene aluminum-ion batteries as their main power source since they can charge 60 times quicker than lithium-ion batteries and store a lot more energy than pure aluminum cells. For instance, AA batteries can be recharged in a minute and coin-cell battery in 10 s using graphene aluminum-ion cells.

6.3 Graphene in Solar Cells

In 2017, scientists from Massachusetts Institute of Technology (MIT) successfully used G into solar cell. For current density and energy conversion efficiency, the researchers established that the G-solar cell was equivalent to other cells completed with aluminum and indium tin oxide, though slightly less efficient than cells made of aluminum. An apparent cell is expected to achieve worse against an opaque aluminum-based cell [35]. A bendable, clear solar cell, which attached to some area (transport, clothing, document, electric items, and many more) has unremarkable electrical characteristics, has been designed. In addition, other researchers are investigating the theoretically feasible ability of graphene solar cells to produce electricity from raindrops.

6.4 Graphene in Thermoelastic

The Seebeck effect occurs after energy is pushed to any electrical conductors/semiconductors that are incompatible with one another. Electrons move from the hot part to the cooler section as a result of the thermoelectric effect, creating electricity. Though, heat produced through the process is very little and is frequently measured in microvolts. Although it essentially lost heat from the motors, it is believed that it can be utilized to capture it. When coupled with graphene, the strontium titanate-produced Seebeck effect can almost be doubled by five.

6.5 Graphene in Alcohol Distillation

Big water molecules can travel through glass thanks to the interesting and unique physical properties of graphene, but helium molecules cannot. Andre Geim, one of the originators of graphene, and Rahul Nair of the College of Manchester demonstrated that graphene can successfully distill ethanol by normal temperature with no vacuum required in this processes by attempting to seal a vodka bottle with a graphene membrane they developed. This space can be used to filter alcohol, water, and other chemicals.

6.6 Drug Delivery Using Graphene

For cancer patients, graphene that has been functionalized is utilized to deliver chemotherapy medications directly to tumors [36]. Delivery methods based on graphene are more effective against cancer cells and less harmful to healthy cells. Anti-inflammatory medications are conceded using mixtures of graphene and chitosan, with promising results. Drug delivery is not just for the treatment of cancer.

6.7 Graphene in Cancer Treatment

The early stages of cancer can also be detected via graphene. Furthermore, it can stop the growth of many cancer types by impeding normal tumor development or inducing autophagy, which results in the death of cancer cells [37].

6.8 Graphs for Gene Delivery

By transferring foreign DNA into cells, gene transfer is a technique for treating various genetic illnesses. As has been the case with medication delivery, it is anticipated that GO customized with poly-ethyleneimine also be utilized for those applications and has low cytotoxicity.

6.9 Graphene in Photo-Thermal Therapy

In photo-thermal therapy (PTT), aberrant cells are removed from the target area of the body by being exposed to a particular substance that produces heat that can kill the cells. Graphene oxide improves PTT's efficiency in many conducts. This will be utilized for concurrently delivering chemotherapeutic medicines and PTT radiation to tumor cells [38]. Chemotherapy and PTT used in this manner are more efficient than either treatment alone. For cancer cell bioimaging during PTT, a reduced graphene oxide nanocomposite (QD-CRGO) will be utilized. The use of graphene oxide functionalized with biocompatible porphyrin for photo-thermal therapy killed more those cells in skull tumors than PTT alone, without harming healthy cells, according to a team of researchers from Texas Tech and Texas A&M University [36].

6.10 Monitoring Diabetes with Graphene

Researchers at the Bath University have created unique blood sugar investigation method, for that skin pricking not required, dissimilar to the pricking technique now in use. With at least one hair follicle, this patch, which has a graphene sensor, can operate on a limited area. By removing glucose from the intercellular fluid, it may detect glucose. With this, blood glucose measurements are no longer uncomfortable, and the accuracy of the results should also improve.

6.11 Graphene in Dialysis

Graphene-based membranes have applications outside the energy, nuclear, and food industries. The use of graphene to purge blood of waste, medicines, and chemicals has been shown by MIT researchers [35]. Because it is 20 times thinner than conventional membranes, graphene has an advantage in this case because it shortens the amount of time patients that must undergo dialysis.

6.12 Graphene in the Implantation of Bones and Teeth

A calcium apatite compound called hydroxyapatite is availed for an artificial bone alternative as the regeneration of bone and dental tissues. The inclusion of graphene, hydroxyapatite, and chitosan has improved the alternative material's mechanical and osteogenic properties as well as its strength, corrosion resistance, flexibility, and other properties as contrast with only Hap.

6.13 Graphene for Cell Treatment and Tissue Engineering

Graphene can heal tissue other than bones as well. It has been demonstrated that specific types of graphene are compatible with human mesenchymal cells and osteoblasts and that they share characteristics with the physiological milieu of the cells. This technique improved cell growth, proliferation, and differentiation while leaving unaffected cell viability [39]. For tissue re-engineering to enhance the lives of persons with neurological illnesses or neurodegenerative diseases, stem cells are very crucial.

6.14 Graphene for UV Sensors

UV sensors are utilized to sense dangerous UV radiation which leads to skin problems or even cancer. UV sensors be utilized for a variety of applications, including environmental monitoring, optical communications, and the military. While graphene by itself does not have a high photosensitivity, when coupled with other materials, it produces flexible, transparent, and cheap UV sensors that are ecologically benign and will soon be used in wearable electronics.

6.15 Graphene for the Brain

There is still much to learn about the brain's secrets. By observing the electrical activity of the brain, a graphene-based device might enable researchers to learn a lot about these unanswered questions. This new technology does not impair brain function and can hear frequencies that are below the threshold of earlier technologies [37]. The technology may aid researchers in understanding the causes of epilepsy episodes and creating patient treatments, in addition to helping them better understand how the brain functions [40]. Additionally, as more is learned about the brain, new brain–computer interfaces that can be used to operate prosthetic limbs and other devices may be developed.

6.16 Graphs in HIV Diagnosis

Even with all the advancements, there are still numerous problems with existing HIV detection techniques. Although these methods take longer to develop and are more expensive than the antibody method, almost a month after the patient has the infection, they can either identify the antibodies in the body or find the virus itself. The Spanish National Research Council has developed a silicon- or graphene-based biosensor that detects the HIV p24 antigen and incorporates gold nanoparticles. When compared to current testing, the new technique can detect the virus 100,000 times earlier, up to one week after infection. Additionally, test results are accessible five hours after the test [40].

6.17 Graphene Biosensors

The capacity of graphene to detect minuscule amounts of chemicals is one of its advantages. In a very large volume, it can find even a single molecule. Biosensors prepared by G, GO, and rGO can detect DNA, ATP, dopamine, oligonucleotides, thrombin, or other molecules with incredibly high sensitivity [41]. Numerous medical businesses already sell graphene-based medical sensors.

6.18 Bactericidal Graphene

Because it damages the cell membranes of microorganisms including bacteria, viruses, and fungi in between its outer layers, graphene is a good antibacterial substance. The best antibacterial activity among graphene derivatives is demonstrated by graphene oxide and reduced graphene oxide. To further boost its antibacterial effects, GO can also be combined with silver nanoparticles.

6.19 Body Scans with Graphene

In contrast to X-rays and T-waves works for scans, this is safe for individual use. Though, sometimes T-waves, referred to as THZ radiation, are difficult to both make and detect [39, 42]. The good news is that CVD graphene can identify THZ radiation with a few adjustments and other materials. This will eventually lead to both safer body scanning and highly speedy Internet.

6.20 *Graphene in Nuclear Power Plants*

In addition to being expensive to make the production of profound water for nuclear power plants of cooling reactor produces one million tons of CO_2. A more cost-effective and ecologically friendly method of producing heavy water has been found by researchers at the College of Manchester: graphene membranes. The team's leader, Dr. Lozada-Hidalgo, believes that despite the nuclear industry's usual reluctance to new technology, this discovery is significant and will soon be adopted by that industry.

7 Nanocomposite of Graphene and its Application

Electrochemical sensors, aircraft, solar cells, supercapacitors, biomedical, and environmental applications all use graphene-based nanocomposites as special materials. Due to its uniform functionalization and functional repeatability, graphene is chosen over carbon nanotubes (CNTs) or fullerenes in sensing applications [43]. Due to the amazing material characteristics of elasticity limit, strengths, electronic conduction, thermal conduction, optical properties of polymer nanocomposites (PNC), research on PNC has increased over the past ten years, and their applications are expanding significantly. Conventional complex arrangements typically include major quantity filler (50 vol. %) bound in polymer matrix, as well as a modest number of inorganic particles with sizes smaller than 100 nm and relatively greater surface region scattered throughout polymer template. Although, micron-sized graphene may be scaled up for mass production. This makes composite materials based on graphene interesting for a wide range of applications [28].

Large strength, elasticity, higher electronic, thermal conduction and stability, more aspect ratio, huge gas permeability, and better geometric firmness are just a few of the many attractive qualities of graphene [6–12]. By incorporating graphene at a modest volume fraction, the characteristics of polymers can be significantly enhanced. Additionally, graphene is being employed for less volume percentage and more surface-to-volume ratio compared to CNT. It is more effective for enhancing a variety of polymer matrices' characteristics. From a precursor of graphite, graphene can be created in vast quantities through oxidation. As a result, graphene-based polymer nanocomposites have piqued significant global scientific interest. Epoxy [40], PMMA [21], HDPE [11], polystyrene [13, 14], and nylon [12, 15–18] are only a few of the polymers that have been employed as matrices in the creation of graphene polymer nanocomposites. Special overviews for creation of graphene-based nanocompounds are given by Malucelli et al. (2016) [43]. It is important to know about effectiveness of graphene spreading on polymer matrix in enhancing the properties of nanocomposites that is closely correlated with this quality [44]. The aspect ratio of graphene filler has a direct impact on the characteristics of a composite.

In order to create fresh resources for alternative energy supply, graphene-based nanocompounds are more and more being used. As instance, (i) graphene-based nanocomposites perform better in lithium-ion batteries because of large power and energy density as well as quick charging rush for H_2 fuel cells; (ii) graphene electrode for enhancing electro-catalytic performance; and (iii) graphene-based compounds already in use for photo-volatilization in solar. Understanding the fundamental of physico-chemical properties of nanocompound requires their characterization. Different businesses use various methods to create the many types of graphene materials that are sold on the market. These graphene are anticipated to differ greatly from one another in terms of flakes width, thickness, and imperfection. In order to obtain knowledge for a variety of components disturbing the nanocompounds microstructure and various methods for altering filler area in addition to synthesizing polymer nanocompounds require strong analysis of those methods and properties.

The dispersion, supply, and arrangement of nanocomposites inside polymer matrix have all been studied using various methodologies. The measurement of nanocomposites has been demonstrated to benefit greatly from a variety of techniques, including optical microscopy, X-ray diffraction, Raman spectroscopy, scanning electron microscopy, high transmission electron microscopy, and atomic force microscopy [44]. Additionally, it is frequently required to use more than one characterization method to completely describe the nanocomposite material. Mechanical Characteristics of Nanocomposites Based on Graphene: When compared to conventional composites, graphene-based nanocomposite materials show a considerable improvement in mechanical characteristics. Many nanocomposites have been strengthened mechanically with the help of graphene. When compared to conventional composites, graphene-based nanocomposite materials show a considerable improvement in mechanical characteristics. Many nanocomposites have been strengthened mechanically with the help of graphene. For instance, adding up relatively few weight percentage of graphene increased the tensile strength of baseline epoxy by almost 40%. The crosslinking density of the nanocomposites is increased by the presence of nanoparticles within the matrix, which significantly improves the mechanical properties. Those characteristics are mostly connected to number of sheets and internal flaws in arrangement of the graphene. Monolayer graphene sheets, for instance, have outstanding mechanical characteristics.

As a result of high surface area that can interact through polymer matrix, graphene-related materials have the potential to deliver relevant performance increases at modest loadings, which is supported by this information. For mechanical performance, an ideal loading was found to be around 0.4 wt% for both materials [43, 44]. Epoxy nanocomposites were created by King et al. by adding 1–6 wt% GNP to the epoxy. Typical macroscopic measurements were used to test the tensile characteristics of these composite materials. Modulus and creep compliance were also measured using nanoindentation. These macroscopic findings demonstrated that adding 6 wt% of GNP to an epoxy composite enhanced the tensile modulus from plain epoxy's 2.72–3.36 GPa. The modulus outcomes of nanoindentation exhibited the same pattern. Polyvinyl alcohol (PVA) composite fibers reinforced with graphene reduced from graphene oxide were created by Li et al. Following reduction, the majority of oxygen-containing group can be taken out of graphene oxide, creating rGO. In particular, the tensile strength and Young's modulus of the 2.0 wt% rGO and PVA composite fiber improved to 244% and 294%, respectively, in comparison with neat PVA fibers. The PVA/rGO composite fibers showed a considerable improvement in mechanical parameters at low rGO loadings.

For biomedical applications like tissue engineering, medication delivery, and cellular treatments, a variety of polymeric nanocomposites are used. A variety of property combinations can be produced to imitate the structure and qualities of natural tissue because of the special interactions between polymer and nanoparticles.

7.1 Applications of Nanomaterials-Based Graphene (GN) in Neural Tissue Engineering

An incredibly appealing method for treating neuronal injuries and disorders involves using graphene distinctive plane, electronic effects to imitate intrinsic stimuli and promote difference of stem cells through neurons [45]. GN-based products have been proven to encourage stem cells to develop into neurons and increase their pace of proliferating. However, the precise mechanism underlying graphene's impact on brain stem cell development is still understood. In this article, we cover various strategies that scientists have employed to encourage neuron discrimination from stem cells in addition to potential prospect of connected research.

Neural stem cells (NSCs) were grown on ginseng-reduced graphene oxide nanosheet in an effort to increase its biocompatibility and electron transfer capacity [25]. Ginseng extract was used for support and Fe foil served as catalyst in the reduction of GO sheets, resulting in addition of ginsenosides, flavanones, starch on exterior, and formation of denser layers. Additional compounds were shown to promote neuronal development and proliferation. In general, cell density of ginseng-rGO is about ten times more than purified graphene oxide after three weeks of incubation. When compared to glial cells, ginseng-rGO also showed more number of neurons, despite the fact that the cell displayed same percentage of pure graphene oxide [46, 47]. Those findings demonstrated that biomolecule functionalization on graphene-based nanomaterial might produce helpful chemical indications, enhancing graphene capacity for promoting NSC dissimilarities in neurons.

GO was chosen over pure graphene because it can assemble laminin more efficiently. The test sets included positively charged glass with graphene coating, laminin, monolayer of nanoparticles, nanoparticles, and graphene. It was demonstrated that GO with NPs had much higher levels of neural marker expression than naked GO. Maintaining stem cells requires communication between the cell's surroundings and 3D vibrant network of macromolecules. For interconnected 3D neural networks, 3D GNs offer good electrical interaction between the material and neurons, resulting in greater conductivity and electroactivity. They also enable cells to grow in 3D milieu for steer to particular lineage. For instance, Shah et al. looked at how differentiation of NSCs into oligodendrocytes was affected by GO density on 3D nanofibrous arrangements [45, 47].

Polycaprolactone (PCL) was used to create 200–300 nm electro-spun fibers that were subsequently composed on glass support and covered with GO at various quantities (0.1, 0.5, and 1.0 mg/mL). All supports were covered by graphene oxide with no nanofibers, and it was discovered that less GO clung to them because of their smaller surface areas, which indicates a strong similarity between PCL and GO. The analysis concluded that supported nanomaterials showed much oligodendrocyte separation even as lesser glial cell and neuron isolation [49]. Additionally, at higher GO concentrations, there was a much distinct appearance of myelin vital protein, which is advantageous for neural regeneration. Interdependent result for nanomaterial scaffold and GO conduction on NSCs was capable for balancing in neural tissue manufacturing as evidenced by PCL-GO, which demonstrated more than twice the quantity of oligodendrocyte marker Oligo version compared to PCL/GO alone[48, 49].

7.2 Drug Delivery Software

An optimized drug delivery systems (DDS) principal objective depends on transport healing mediators within the sick section in manageable way with less negative results on strong tissues. Some chemotherapy medications may not dissolve well in water, and their localization into tumors is not always precise, resulting in severe adverse effects on tissues that are not the intended target. Owing toward their suitable large surface region, biocompatibility, ease of functionalization, G and its derived, mainly graphene oxide, have received the most attention among other nanocarriers within area of nano-medicine as bacterial inhibitors, imaging distinct agents, and drug/gene release structures [50, 51].

Furthermore, the ability of graphene nanostructures to absorb a significant amount of near-infrared (NIR) light makes it possible to use those for photo-thermal treatment purpose. Thus, graphene-based nanomaterial has interdependent impact to exist like heat-reactive nano-sized drug carriers in healing purposes such as cancer by fusing together all potentials of transport pharmaceuticals and increased photo-heat alteration. Other kinds of therapeutic agent-loaded modified graphene-based nanoplatforms, on the other hand, might be identified as stimuli-responsive arrangements in support of effective drug release [50]. According to the various forms of environmental stimuli, a variety of documents based on stimuli-responsive graphene-based nanoparticles are reassessed based on following parameters (like, pH, light, redox, magnetic field, and temperature).

7.3 Specific Drug Delivery

Currently, a wide range of investigations has been presented us with a number of drug release processes in addition to specific techniques.

Graphene-based materials could be used to create tailored DDSs, just like other nanosystems that have been used for drug delivery. Histidine (His) was used in a unique way by Zhang et al. to mediate hydrothermal extension of the unstructured zinc oxide (a-ZnO) shells on gold nanomaterial (Au-His@a-ZnO). They inserted Au-His@a-ZnO NPs on the surface of PEGylated graphene oxide using carbodiimide crosslinker chemistry (PEG-GO). This work involved the creation of Apt@GO@Au-His@a-ZnO@DOX (Apt stands aptamer) nanocompounds, which demonstrated high doxorubicin (DOX) carrying capacity together through near-infrared/pH-sensitive drug delivery, allowing metal-drug composite for dissociate to release anti-cancer ions of Zn^{2+} in less pH surroundings (endosome/lysosome of tumor cell). Those also showed excellent biostability and aptamer-enhanced lung carcinoma cell attachment [52]. Compared to untargeted controls, the precise binding facilitated cellular absorption into the epidermal growth factor receptor (EGFR)-mutated tumor location. This study used Apt@GO@Au-His@a-ZnO nanocompounds in vivo to demonstrate significant focused drug release and strong anti-cancer efficiency using A549 cells (human lung adenocarcinoma cells) in turmeric mice. The research's use of mixed-use nanocompounds (Apt@GO@Au-His@a-ZnO@DOX) produced highly effective focused photo-/chemotherapy for lung cancers.

One more trial showed, sound nanocarrier capable of effectively delivering a medicine during cancer treatment was created using quantum dot-based GO nanomaterial. An effective nano-cargo was created by conjugating GOQD with chitosan-functionalized folic acid in order to use this DDS in cancer therapy (FA-CH). That revealed the synthesized FA-CH-GOQD is an effective, adaptable nanocarrier toward release of DOX [50].

For MRI and DOX delivery, a folic acid besieged method established on graphene oxide-covered Fe_3O_4 nanocompounds is adopted. The FA-Fe_3O_4@nGO-DOX system may be a useful and reliable substance for targeted medication delivery. Investigations into FA-Fe_3O_4@nGO-DOX nanoplatforms' potential to support cell survival revealed Callisaurus cell line/MGC-803 preferential perception. The careful nanomaterial intake into MGC-803 cells with folic acid receptor and pH-mediated drug release were used to demonstrate the selective death of tumor cells.

Additionally, it has been suggested that G quantum dots and Fe_3O_4 nanocompounds bound among the lectin protein Concanavalin-As may be a promising contender for identification of tumor cells and the focused delivery of DOX targeting HeLa cells [53]. GQD-ConA@Fe_3O_4 was the abbreviation for the entire system. It has been demonstrated that the incorporation of Fe_3O_4 into the nanocarriers causes drug concentrations in HeLa cells to enhance by greater than double in the presence of an external magnetic field. In addition, the targeting function of Concanavalin-A in nanomaterials was confirmed after demonstrating HeLa cells' 13% increased susceptibility toward drug in comparison to natural cells.

Enhanced fluorinated graphene oxide (FGO) possesses the following qualities as a hugely significant drug carrier: The following characteristics of the drug delivery system were prepared: high drug loading capacity, switchable fluorescence, water solubility, regulated and pH-sensitive drug delivery, large NIR absorption, improved photo-thermal effects, and desired drug release, nano-configuration. FGOs were initially adjusted in folic acid acting like desired material by purging O_2 through nanosheets. Additionally, the photo-thermal performance was improved by modifying fluorinated G into a nanoscale arrangement using sp^2 carbon. Notably, endocytosis into cells is facilitated by the FGO's microscopic size. Quickly, DOX was installed on FGO-FA. FA ensures that the nanoparticle is delivered to cancer cells that have FA receptors on them, and the remaining portion of the particle causes the release of DOX when there is intracellular acidity [53, 54].

Energy transport among GO, FITC, and ATP was noted within a three-part system known as GONsFITCATP (GONs: graphene oxide nanosheets, FITC: fluoresce in isothiocyanate, ATP: adenosine-5′-triphosphate). In order to deliver DOX to tumor cells, a focused drug release scheme build on graphene quantum dots (GQDs) connected to biotin as a selecting unit was developed. GQD was biocompatible, and biotin-linked GQDs burdened among DOX in the A549 cell line demonstrated more absorption against free DOX or GQDs-DOX.

For the delivery of camptothecin (CPT), methods related by decorated magnetic nanomaterials on graphene oxide covered in mesoporous silica were created. The carriers demonstrated a regulated and pH-responsive drug release and have a 20% capacity for drug loading. It was discovered in this investigation that the synthetic structures had a significant amount of success against HeLa cells. Additionally, with appropriate magnetic characteristics and more adsorption capacity, the adaptable nanosurface can be used for tumor chemotherapy [55].

7.4 Graphene in Smart Gene Delivery System

A foreign DNA is effortlessly sent to a cell using a smart gene delivery system (SGDS) on behalf of gene therapy or investigation. SGDS is categorized the same as chemicals (such as lipids or nanomaterial carriers), biologicals (such as viral or bacterial vectors), and mechanicals (such as electroporation, microinjection, and biolistics) depending on the mode of the gene's entry into the cytosol [54, 56]. Gene delivery through chemical means is more typical and uses organic nucleic acid complexes including lipid, cationic polymer, and calcium phosphate. Although biological approaches rely upon creating viral gene discharge system, for that a particular gene is infected into the target cells (s). However, using electroporation, microinjection, and photo-transfection, exposed nucleic acid is delivered into cells using mechanical methods. The successful outcomes of a smart gene delivery system primarily found scheduled transfer of DNA for chosen organs in terms of system's effectiveness. Various parts considering scientific or research emphasis are experiencing a growth due to the development of nanotechnology in the twenty-first century [56].

8 Challenges to Produce Value-Added Graphene Nanomaterial Products

Producing graphene on a large scale has its own difficulties. While graphene has received recent attention, it is important to remember that other materials face similar difficulties. Do not disregard the challenges posed by the dispersion and alignment of graphene, which have recently started to be utilized in products. Commercial-scale 3D printing has faced several difficulties in the past. In reality, no matter the material or industry, there are always production obstacles [57]. So why is graphene receiving so much attention? The so-called wonder material is often portrayed as the substance that can solve all application problems and be used to increase productivity in virtually every field of science and technology [58]. Graphene is nevertheless aware of the numerous difficulties that many manufacturing sectors encounter.

There are several different types of graphene (even though this is disputed, the general consensus within the industry is now that there are a family of graphene). Secondly, different processes for making graphene result in extremely varied results. Thirdly, the graphene that can be used in products is not the same as the raw material used to make it. There are many distinct varieties of graphene, and each is beneficial in its own way. Single-layer graphene is preferable for electronics, while some of the larger layer counts (but less than 10) are more affordable and better as additives. Unfortunately, neither end-user markets nor large organizations in general have received adequate information about graphene, and the majority of those looking to use it are unaware of what they are purchasing [58]. Because of this, even if a good form of graphene is available for someone's application, they could not always select the right variety, leading to poor results and a drop in market trust. As more research is being done to better inform decision-makers and more end-user products are now becoming a reality, confidence in graphene is starting to return.

Chemical vapor deposition (CVD) and exfoliation from graphite are the two main methods used in commercial manufacture of G. A solitary sheet of G is deposited using the bottom-up CVD technique on a substrate. Due to its single layer, this graphene is undoubtedly the "highest quality", but it is also often more expensive and can only be produced (at the moment) in smaller amounts [59]. Due to challenges in extracting graphene from the substrate on which it originates, it must frequently be deposited on a customer's substrate of interest in-house.

As a result, it is not the most scalable, yet it works perfectly for specific uses, like electronics. You also have exfoliation techniques, though. These processes convert graphite to graphene. Graphite's intermolecular connections are broken down by strong chemicals, mechanical stress, sun radiation, or high temperatures, but this makes the process much more unpredictable. This typically results in products with inconsistent layer distributions between batches. Even though this type of graphene is typically regarded as being of lower quality, it is significantly more inexpensive, can be produced in considerably larger quantities, and is nonetheless acceptable as an additive in a range of composites and applications [59, 60].

The second aspect to consider is how graphene is used in a product. Before being used as an additive, it must first be functionalized in order to be stable within the composite matrix. The so-called quality is frequently meaningless (since the properties change nonetheless) because the properties of the usable graphene differ from those of the raw material, which is why exfoliated graphene has lately become more usable. The same is true for further graphene derivatives, like rGO and partly functionalized GO [60].

Overall, there are a few issues to resolve, but they are no more significant than those that face any other industrial sector. Because everyone is aware of graphene and is aware of its potential, there is a difference in that everyone is so eager for things to work the first time. Additionally, many mention a lack of standards. Though no physical or measurement standards are currently in existence, they are being developed and will take time, just like they do for any other substance. Again, because it is graphene, researcher anticipates everything to happen right away, but every material must go through a protracted process until all standards are met. In conclusion, neither the manufacturing difficulties associated with making graphene nor its fundamental differences from other materials are particularly noteworthy.

The adoption of graphene may be slowed by a few problems. The restricted manufacturing volume is one such element. Although a variety of ways to produce different kinds of graphene are growing, their combined volume production remains limited. The graphene industry's major challenge will be to achieve volume manufacturing within the next two to five years. The uniformity of the materials and the cost of production must be the main concerns [59, 60]. Since graphene's debut on the market, costs have decreased significantly. The cost of sheet graphene has decreased to a third over the last two years, while the cost of powdered graphene (including liquid graphene) has decreased to a quarter of its initial cost. However, the high initial material cost encourages the development of high-margin applications and applications that make use of a variety of graphene's features.

Chemical vapor deposition (CVD), a time-consuming, expensive method which made use of dangerous chemicals to develop graphene as a single-layered with heating platinum, nickel, or titanium carbide in the presence of ethylene or benzene, was until recently the only way to produce large areas of graphene. There was just one substrate available for crystalline epitaxy, and that was metal. Due to those manufacturing problems, graphene was originally not available for commercial use or advanced research. It was challenging to employ CVD graphene in electronics because it was challenging to remove the graphene sheets from the metallic support exclusive of hurting the graphene [59].

Graphene can be successfully separated from the metallic board on which it is formed, and the metallic board can theoretically be used an endless number of times for subsequent applications, according to research from 2012. As a result, less harmful waste is being generated throughout this process. Additionally, the graphene that was extracted using this method was of a quality that could be applied to molecular electronics. Since that time, research on the synthesis of CVD graphene has improved quickly, rendering the material's quality unimportant to scientific recognition that at present based on the cost of metal support used as a foundation [60].

However, researchers are working towards developing reliable methods for producing graphene on specific supports with organize more than flaws like ripples, doping levels, and domain size, as well as the number and comparative crystallographic arrangement of the graphene sheets.

9 Conclusions

A detailed study concerning graphene nanomaterials, its manufacturing processes, numerous potential value-added applications, and challenges in assorted fields has been discussed in this chapter. The physico-electrical properties of graphene which led to its relevant uses in various fields have made graphene the supermaterial of this century. A number of techniques, including ball milling, exfoliation, chemical vapor deposition, and physical vapor deposition, can be used to create graphene nanomaterials. Electrochemical sensors, aircraft, solar cells, supercapacitors, biomedical, and environmental applications all use graphene-based nanocomposites as special materials. Due to its uniform functionalization and functional repeatability, graphene is chosen over other carbon materials in sensing applications.

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