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Review—Chemical Structures and Stability of Carbon-Doped Graphene Nanomaterials and the Growth Temperature of Carbon Nanomaterials Grown by Chemical Vapor Deposition for Electrochemical Catalysis Reactions

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Abstract

Carbon nanotubes (CNTs) have been studied extensively utilizing the catalytic chemical vapor deposition (CCVD) process for several decades. CCVD is seen to have a better degree of control and scalability. CNTs have proved to be useful in single-molecule transistors, Scanning Electron Microscope (SEM) tips, gas and electrochemical storage, electron field emitting flat panel displays, and sensors. This paper summarizes various stabilizing agents such as cobalt ferrite and molybdenum disulphide that can increase the electrochemical activity of the Carbon Doped-Graphene Nanomaterials as Graphene doped with carbon shows a significant improvement in the properties in various aspects. We also investigated the electrochemical applications where CNTs are used as a prerequisite. Carbon nanotubes are seen in biosensors, energy storage, conductive plastics, and power fuel cells. Carbon nanomaterials’ influence on symmetrical and asymmetrical supercapacitors, carbon nanomaterials to power dye-synthesized solar cells, and the importance of CVD in the synthesis of carbon nanomaterials were also investigated.
1. Introduction

Extensive study of Carbon nanotubes (CNT) using the Catalytic-chemical vapor deposition (CCVD) technique was done for the past few decades, creating CNT variants of different crystallographic configurations. Extensive research was done on the extraordinary properties of CNTs in mechanical, electrical, and optical fields. Observation of single and multi-walled CNTs was done late in the '90s. Later, a few walled CNTs were discovered, showing remarkable mechanical and electronic properties. CNTs were found to grow several cm, exhibiting extraordinary aspect ratios. A wide range of CNTs applications was investigated and enlisted. CVD was considered the most prominent technique for bulk production [1]. CVD was widely adopted since it was the easiest and most economical approach for preparing CNTs. CNT synthesis by using CVD included catalyst deposition on a substrate, and then chemical etching on thermal annealing was done for the nucleation of the catalysts. A distinct CNT formation mechanism showed that the precursors might remain intact during the C-C bond formation. Methane acetylene, ethane, and ethanol were the most common carbon sources used to analyze CNT growth by a CVD method. The use of several catalysts increased the production and quality of CNTs. [2] Bimetallic and trimetallic compound catalysts showed major scope for the preferred development of carbon nanotubes. The length and breadth of the under layer and the material characteristics affected the nanotube’s growth rate to a vast extent. It was also advised to utilize high melting catalysts to promote the preferred development of CNTs suitable for device applications [3].

Plasma-enhanced chemical vapor deposition (PECVD) provides lower operating temperatures and higher product quality than thermal chemical vapor deposition (thermal CVD). Inelastic collisions between electrons and gas molecules occur throughout the PECVD process, resulting in the production of reactive species. DC discharge, RF discharge, and microwave excitation create plasma in the PECVD process. Microwave plasma also offers the advantages of high reactivity, quick heating, and superior controllability, among other things. To make plasma, a microwave power source is often utilized as the excitation source, converting microwave power into internal energy of gas molecules [4].

Carbon nanotubes and less crystalline carbon nanofibers (CNFs) are good demo species for accessing weak physics and, due to their unique properties, may play an important role in emerging nanotech. Arc discharge and CVD are only a few ways for growing CNTs developed. However, due to the difficulty and cost of specific management of CNTs due to their size, very few technologies allow for the controlled production of nanotubes directly on a substrate. Plasma-assisted chemical vapour deposition has achieved selective, aligned development of CNTs on Substrates made of silicon and glass (PECVD). [5]

Graphite is the most frequent and stable of the naturally occurring allotropes of carbon under ordinary circumstances. Graphene is a two-dimensional substance with hexagonal honeycomb-shaped lattices of sp2 hybridized C atoms. It also attracted the interest of many technological fields due to its unusual chemical, mechanical, and electrical characteristics. [6]
Doping Graphene with most of the elements makes its electrocatalytic activity increase. Guano (a natural material) was used as a dopant for Graphene instead of expensive chemicals. Guano contains many elements in it. It is cheap and can be handled easily. It was said in previous studies that a time would come when Guano doped graphene would be utilized instead of platinum for running fuel cells. The prepared Guano doped graphene samples were tested by SEM, X-ray Photoelectron Spectroscopy (XPS), and Hydrogen Evolution Reaction (HER). SEM scans revealed typical exfoliated structures consistent with prior research and demonstrated the effective thermal exfoliation of all samples. The Raman spectroscopy of the doped graphene samples indicated the type of hybridization of the carbon atom (Sp2). The doped Graphene sheets also showed better performance than non-doped Graphene for both Oxidation-Reduction reactions and HER reactions. Even bird-dropping doped graphene sheets are highly valued and used in fuel cells. [7]

Faulty carbon-doped boron nitride nanosheets (C-BN) were discovered to have good electrochemical performance and endurance in N2 fixing. Recently ammonia (NH3) has been produced by a nitrogen reduction reaction (NRR). Here they created faulty C-BN nanosheets for NRR, and they concluded that the ideal active site for the NRR could be unsaturated Boron. The C-BN nanosheets have high reactivity due to the doping of carbon and the structural defects formed due to the doping. On comparing normal electrocatalysts to C-BN nanosheets, it was found that the NRR performance of the normal electrocatalysts is poorer. So NH3 production using C-BN nanosheets in NRR is preferred. [8]

With the help of chemical doping, we can adjust any material’s chemical and electronic characteristics. Boron and Nitrogen dopants are widely used by chemists worldwide as they have the same C-atom sizes and highlight excellent graphene conduction. [9] Boron-doped and undoped graphene nanosheets exhibit little electrochemical behavior of biomolecules. The behavior of biomolecules like dopamine, uric, and ascorbic acid on the boron-doped graphene sheet’s surface will be studied. Various techniques characterize the obtained graphene nanosheets and boron-doped graphene nanosheets. With the help of the cyclic voltammetry technique and their voltammograms on the glassy carbon surface, the behavior of dopamine uric and ascorbic acid was examined. With boron-doped graphene nanosheets, glassy carbon modified electrodes for biomolecules, the anodic potential was found to be greater. [10] Overall, Boron-doped graphene nanosheets were extremely useful and were recommended by researchers to detect the behavior of biomolecules. [11]

CNTs have been shown to exhibit unique electrical, chemical, and morphological properties that make them particularly appealing for electrochemical investigations. As a result of their structural and morphological properties, carbon nanotubes (CNTs) have distinct electrocatalytic activities and the capacity to promote straight electrochemical properties of enzymatic reactions produced from many other types of carbon compounds [12]. CNTs, in general, improve cathode performance due to their highly porous and very good network. Cell resistivity is significantly reduced, whereas ion transport is drastically enhanced. Carbon nanotubes and high conductivity may be elastic, which is important for electrodes and provides important benefits, particularly if electrocatalysts’ volume changes happen during
functioning. As a result, they provide excellent support for conjugated polymers and metal
oxides, resulting in attractive capacitor substrates. Incorporating nanoparticles into a
precursor material rich in heteroatoms, such as N2 from urea or air, leads to an interesting
activated carbon composite with excellent charge transmission for supercapacitors.[13]

We will be looking into the Stabilization of Carbon Doped-Graphene Nanomaterials, the
CVD process required for the increase in temperature of carbon nanomaterials, the
electrochemical applications at which carbon nanomaterials are used as a prerequisite, and we
will be discussing the results widely.

2. Understanding Stabilizing of Carbon Doped-Graphene Nanomaterials

2.1 Carbon doped graphene nanomaterials

Doping Graphene with most of the elements makes its electrocatalytic activity increase. So,
Graphene doped with carbon results in a significant improvement in its properties. Tests done
on the Carbon doped Graphene nanomaterials revealed typical exfoliated structures consistent
with prior research and demonstrated the effective thermal exfoliation of all samples. The
Raman spectroscopy of the doped graphene samples indicated the type of hybridization of the
carbon atom (Sp2 hybridization). The doped Graphene sheets also showed better performance
than non-doped Graphene for both Oxidation-Reduction reactions and HER reactions. [14]
Coconut-shell activated Carbon (CAC) doped with graphene oxide (GO) was used to prepare
composite materials. Figure 1 demonstrates the above process. Chang et al. [15] developed a
calcium-based organic metal conceptual model for separating CH4 and N2. They concluded
that a greater surface area and size of pores are beneficial for CH4 absorption. Graphene
oxides (G0s) were added on Activated carbons (ACs) [16]

![Diagram](https://mc04.manuscriptcentral.com/jss-ecs)

**FIGURE 1.** Coconut-shell activated Carbon (CAC) doped with graphene oxide (GO) was
used to prepare composite materials.
Putri et al. [17] gave the following conclusion in a review, Heteroatom addition to Graphene can impart photo catalytically advantageous features and further increase graphene’s photocatalytic capability. As of today, heteroatom doped graphene has emerged as an important study sector currently undergoing tremendous advancements, as seen by an explosion in the number of recent publications. The emergence of these novel doped carbon compounds has sparked much interest in their potential uses. Moreover, the complicated chemical microenvironment, the influence of flaws, various dopant structures, and their location on graphene characteristics should be carefully researched better to understand the relationship between dopant atoms and Graphene. As a result, there is still much uncertainty about the link among dopants and their specific involvement in activities improvement.

Carbon and Boron have lots of similarities, so a study of boron doping of Graphene was analysed; boron doping of Graphene was demonstrated to be advantageous in terms of energy since the energy of formation of Boron doped Graphene sensors (BG) in the case of a dopant in gaseous form is Five-point six electron Volts for every atom, that is significantly lower as compared to that of Nitrogen doping which is around eight electron Volts for each atom. Since there are similarities between Boron and Carbon atoms, Twenty-five Boron particles in the groups present are sp2-hybridized for doping done in the plane, allowing the planar graphene structure to be preserved; nevertheless, the grid boundaries are changed because the Boron–Carbon bond is longer than the Carbon-Carbon link. On the other hand, boron-doping that is done out of the plane causes significant deformation in the structure of Graphene because of the dopants at unoccupied sites with BC4 units. Boron-doping adds additional holes to Graphene’s valence band, resulting in increased conductivity and carrier concentration in BG. [18]

2.2 Stabilizing agents for carbon-doped graphene nanomaterials

Graphene doped with carbon can be stabilized by adding several agents. This improves the magnetic, electrochemical, conductive, and several other properties of the graphene nanomaterial. We will discuss a few stabilizing agents used to increase the stability of carbon-doped graphene nanomaterials.

Yong et al. [19] found that molybdenum disulphide nanosheets doped with carbon stabilized on Graphene had high electrocatalytic activity when tested in the case of the hydrogen evolution process. In this research, narrow and rim nanosheets of molybdenum disulphide and carbon-doped in the inner layers and painted onto Graphene were created using a simple solvent-thermal approach. Additionally, the synthesized nanohybrids demonstrated improved durability and stability. In terms of nanomaterials, nanohybrids containing Carbon doped interface regions increased the spacing between the different layers and the percentage of flaws, resulting in greater catalytic activity than MoS2 nanosheets.

Velmurugan et al. [155] investigated a p–n heterojunction reduced graphene oxide/indium tin oxide photoelectrode stabilized by molybdenum disulfide–graphitic carbon nitride (MoS2–
GCN). This was done to detect the neurotransmitter dopamine by photoelectrochemical means. XRD and SEM methods were used to characterize the produced electrodes' physicochemical properties. The UV-DRS experiment confirms that the manufactured electrode has increased photocurrent activity at 490 nm. The addition of molybdenum disulfide to graphitic carbon nitride increased the photo-electrocatalytic detection of the neurotransmitter dopamine significantly. The photo-electrocatalytic detection activity of dopamine in the linear response range of 0.004–1351.74 M with a detection limit of 1.5 nm, is demonstrated by the MoS$_2$–GCN.

A nanocomposite comprising molybdenum disulphide (MoS$_2$) and N/S dual-doped graphene (NSG) was effectively produced by in situ self-assembly employing graphene as an auxiliary agent. The effect of graphene dose on MoS$_2$ morphology has been analysed. The results suggest that adding graphene to nanohybrids improves the dispersion homogeneity and coupling states of MoS$_2$ and NSG, as well as increasing the total number of defects. When the graphene's dosage is 22 milligrams, the sample performs best, with a high specific capacitance. [156]

As a result of the distinctive architectures of carbon-based nanomaterials having enormous surface areas, strong electrical conductivity, and outstanding mechanical qualities, CNTs are frequently employed to create different sensors. Because they are naturally insoluble in water, how to dissolve and distribute them looks particularly relevant for creating electrochemical sensors. [20]

Graphene stabilised with organic quinones because of their quick and reversible oxidation and reduction kinetics through a chemical method are emerging as low-cost and sustainable alternatives to traditional semiconductive materials.[167]

Cu etching is a critical operation in Graphene production with greater area using CVD since it is necessary to eliminate Cu catalyst and put Graphene to the targeted substrate for future uses. Despite its usefulness in manufacturing graphene sheets of greater quality, the Cu etching approach has received far less attention than doping or transfer procedures. In most cases, the Cu etchant contains a powerful oxidizing agent that quickly changes metallic copper to a copper ion with two positive charges. According to Sang et al. [21], introducing benzimidazole to etching solutions lowers the activity of Cu-etching solutions by generating a stable complex between benzimidazole and copper ions. Figure 2 demonstrates the above process. Without further doping operations, the resultant graphene film formed using a Cu stabilizing agent has a lower sheet resistance. Because of its superior conductance, physical durability, high surface area, and various mass-transfer pathways, Graphene has much promise in electrocatalytic water splitting. To make transition metal carbon-based composites, we developed a simple technique for encapsulating CoFe$_2$O$_4$ with spinel structure in GA. CoFe-PBA particles were injected into graphene oxide flakes to generate graphene hydrogel, subsequently dried in cryogenic conditions to form aerogels, and heat-
treated in a nitrogen atmosphere at various temperatures using Prussian blue analogs as precursors [22].

Carbon doping in Strontium Titanate (SrTiO$_3$) by thermal treatment of graphene oxide with SrTiO$_3$. This doping improves SrTiO$_3$ optical absorption and decreases its band gap. Strontium titanate (SrTiO$_3$) is observed as an excellent photocatalyst because of its appropriate n-type semiconducting properties and its preferred Ti–O–Ti bond connectivity. Chromium and Lanthanum play an important part in increasing the visible light response of SrTiO$_3$. Under visible light degradation, C-doped Strontium Titanate allowed sewage and biological contaminants to deteriorate. Therefore, SrTiO$_3$ can serve as a potential photocatalyst for environmental reformation. [23]

![FIGURE 2](image-url)

**FIGURE 2.** Concurrent Etching and Doping by Cu-Stabilizing Agent for Graphene.

Thomas et al. [24] showcase a few latest and significant advancements on MoS$_2$ nanofibers (SAC-MoS$_2$) doped with carbon as an electrocatalyst that can be used for hydrogen evolution reaction (HER) from water in their study. In particle morphology, 2D nanosheets improve volume-surface area ratios and offer specific surface locations for dispersing foreign atoms. Because of their distinct yet controllable electronic and steric properties, one of the novel ways is to put atoms of catalyst activity on two-dimensional nanofibers as Single-Atom Catalysts (SAC). The type of dopants, doping sites, and polymer types of molybdenum disulphide nanosheets are demonstrated to be decisive variables in the general catalytic performance of these functionalized carbon nanostructures.

For its exceptional electrochemical, optical, and magnetic capabilities, Graphene and its equivalent, MoS$_2$, have been used for ‘green energy’ purposes in recent years. Their enormous success, along with practical possibilities in various disciplines, has prompted the development of novel 2D nanomaterials that push the limitations of current Graphene-based systems. The coupling of inactive graphene material with active MoS$_2$ in a circuit element offers new avenues for improving energy device performance and circumventing existing restrictions.[25]
Lee et al. [26] described a chemical approach for making size-controlled SmCo$_5$ nanoparticles and covering them with a layer of N doped graphitic C to protect them from air oxidation (NGC). SmCo-O nanoparticles were painted with poly-dopamine and were annealed to generate SmCo-O/NGC nanoparticles. [27] The research demonstrates a unique approach for producing and stabilizing SmCo$_5$ nanoparticles enabling elevated nanomagnetic uses over a temperature range. The results showed efficient protection of the SmCo$_5$ particles from air oxidation when stabilized by adding the doped graphitic carbon.

Behnam et al. [28] investigated the Sodium-do-decyl sulphate (SDS) stability over nanoparticle sheets of 2 different diameters as fillers within standard electrical conductor adhesive (ECA) composite. They were able to preserve the one-layer layout of graphene layers and avoid stacking inside the composites using this quasi-modification strategy, resulting in considerable electric characteristics increase of ECAs with obviously lower filler concentration. Incorporating tiny and huge Sodium-do-decyl sulphate modified Graphene into traditional ECAs containing flakes of silver resulted in lower resistivity values, whereas the conventional ECA required at least some silver flakes to be electrically conductive.

Working on Gelatin stabilized gold nanomaterials coated with reduced graphene oxide nanohybrid, Balamurgan et al. [29] used a very susceptible and specific fluorescent detection of L-Cysteine (L-Cys). The reduced Graphene Oxide / Gold nanohybrid was created using a one-pot hydrothermal approach and was thoroughly characterized using several physical and chemical methods. Because of the recovery of suppressed luminescence of the reduced Graphene Oxide / Gold nanohybrid with L-Cys, the reduced Graphene Oxide / Gold nanohybrid exhibits increased fluorescence activity. The reduced Graphene Oxide / Gold nanohybrid has a lower detection limit and greater selectivity for L-Cys. The following Table 1 compares some stabilizing agents for Graphene.

<table>
<thead>
<tr>
<th>Stabilizing agent</th>
<th>Applied on</th>
<th>Application</th>
<th>Ref</th>
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<tr>
<td>Benzimidazole (BI)</td>
<td>Cu-etchant</td>
<td>Helps in reducing the activity of the Cu-etching solution by producing a stable complex</td>
<td>[21]</td>
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<tr>
<td>Cobalt Ferrite (CoFe$_2$O$_4$)</td>
<td>Graphene</td>
<td>Cobalt Ferrite has excellent photocatalytic activity and shares carbon compounds’ excellent durability and electrical conductivity</td>
<td>[22]</td>
</tr>
<tr>
<td>Molybdenum disulphide</td>
<td>Graphene</td>
<td>Enhances electrocatalytic activity for the hydrogen evolution process</td>
<td>[19]</td>
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</tr>
<tr>
<td>Sodium dodecyl sulphate (SDS)</td>
<td>Graphene</td>
<td>ECAs exhibit a significant improvement in electrical conductivity while having a modest filler level.</td>
<td>[28]</td>
</tr>
<tr>
<td>Gelatin</td>
<td>Reduced Graphene Oxide nanoparticles</td>
<td>Increased fluorescence activity</td>
<td>[29]</td>
</tr>
</tbody>
</table>

### 3. Significance of CVD in Growth of Carbon Nanomaterials

#### 3.1 Historical perspective of carbon nanomaterials

In the early 1950s, a paper published in the Soviet Journal of Physical Chemistry was distributed, showing empty graphitic carbon strands of 50 nanometers in breadth [30]. Followed by noticing a development of filament carbon fibers of 10–200 nm in breadth in 1955 [31]. In the late 1950s, an expansion of the nanoscale cylindrical carbon fibers from n-heptane deteriorates on iron at around a temperature of 1000 °C [32]. The early 1960s showed that the construction comprises moved-up graphene sheets in concentric chambers with the help of electron microscopy and the “graphite whiskers.” [33] The movement of the graphene sheets in nature led to the examination of the erosion properties of carbon. The Electron Microscopic picture plainly showed the presence of multi-walled carbon nanotubes (MWCNT). [34] In the early 1970’s it was reported development of three unique graphitic-like fibers; cylindrical, wound, and inflatable-like. [35] The empty cylinders were found to be MWCNT with the help of TEM pictures and diffraction information. The year 1974 laid the foundation for the detailed outlook of the Chemical Vapor Deposition (CVD) process, development of nanometer-scale carbon strands, and announced the disclosure of carbon nanofibers, including that some were formed as empty cylinders. [36] In the late 1970s, an English science-fiction writer, Sir Arthur Charles Clarke’s science-fiction novel “The Fountains of Paradise,” prescribes the possibility of a space lift utilizing “a persistent pseudo-one layered jewel gem” [37]. In the early 1980s, “The persistent or drifting impetus process” was licensed [38][39]. In the early 1990s, the nanotubes combined empty carbon still up in the air with their gem structure without precedent for the sediment of circular segment release at NEC, by a Japanese analyst [40][41]. In the CVD process by Maganas Industries, Nanotubes prompted the advancement of a technique to incorporate monomolecular dainty to film nanotube coatings. [42] This was followed by the first hypothetical presumptions for the electronic properties of carbon nanotubes. [43][44][45]
In 1993 Bunches driven at IBM [46] and at NEC [47] autonomously found single-divider CNTs and techniques needed to utilize progress metal imputes. In the mid-1990s, Swiss scientists displayed the electron outflow properties of CNTs. [48] [49]. The late 1990s are significant as the first carbon nanotube single-electron semiconductors designed to work at low temperatures were exhibited by bunches at various colleges in Europe and North America. [50][51] In 1998 first carbon nanotube field-impact semiconductors were shown by bunches at Delft University and IBM. [52][53][54]

At the beginning of the 21st century, the first demonstration was observed proving that bending carbon nanotubes changes their resistance [55], and in 2001 the first report on a method for isolating semiconducting and metallic nanotubes. [56] In 2002 the Multi-walled nanotubes were demonstrated to be the fastest known oscillators (> 50 GHz) [57] whereas in 2003, NEC announced stable fabrication technology of carbon nanotube transistors. [58][59]

In the mid-2000s, a model of superior quality 10-centimeter level screen made utilizing nanotubes were shown. [60] The College of California views Y-formed nanotubes as instant semiconductors.[61] The nanotube diode device also saw a photovoltaic effect, which might lead to advancements in solar cells, making them more efficient and, hence, more financially viable. [62] Nanotube sheets were integrated with dimensions of 5 × 100 cm. [63] In the mid-2000s, an electronic circuit around a CNT by an American multinational technology corporation, IBM. [64] Nanotubes were also utilized as a platform for harmed nerve recovery. [65][66] Contraption imagined by a university in North America that can sort nanotubes by size and electrical properties. [67][68]. The late 2000s involved nanotubes joining the infection battery. [69] Synthetic vapor statement across a 10-micron hole in a silicon chip was used to create a single-walled carbon nanotube, which was then used in cold molecule testing to create a black hole-like effect on single particles. [70] In the early 2010s, IBM made a 9 nm carbon nanotube semiconductor that beats silicon. [71] Finally, a Rice University research group reported cultivating another wet-turned nanotech fiber in the early 2010s. That new fiber was made with a modern, adaptable cycle. [72] The filaments described in science have several times the flexibility, electrical, and thermal conductivity of the best wet-turned CNT strands recently disclosed. Analysts built a carbon nanotube computer. [73]

3.2 Understanding Chemical vapor deposition (CVD)

CVD is a deposition via vacuum process utilized to make high-strength materials. It is one of the most used techniques used to produce CNTs. It has a low synthetic temperature and an ambient pressure [157]. Intermittently, unstable secondary effects are conveyed, which are taken out by a gas course through the entire reaction chamber. Micro-fabrication methods utilize CVD to store materials in numerous designs, including polycrystalline, monocrystalline, and uncleanness in shape. [74] These materials can include Compounds of Silicon, Carbon nanotubes, filaments, fluorocarbons, titanium nitride, tungsten, and different dielectrics. CNTs can also be prepared at a low-cost during CVD by renewable biomass resources using materials such as camphor and rice straw [158]. Figure 3 depicts the key steps in the standard CVD production process.
FIGURE 3. Key steps in the standard CVD production process

The growth mechanism of CNTs by CVD dissociates carbon precursors into carbon atoms, dissolves and saturates the atoms present in the catalyst metal particles which then precipitates into carbon deposits. Morphology is affected by the furnace type, size of catalyst Abd carbon precursor type. Metallic catalysts such as Fe, Co, Ni, and their alloys are used for the synthesis of CNTs [157].

Because of its more serious level of control and its versatility, chemical vapor deposition is currently the common amalgamation strategy for carbon nanotubes. Chemical vapor deposition suggests the synergist transformation of a vaporous antecedent inside a durable material at the outer layer of responsive elements or of a ceaseless impetus film going about as a layout for developing material. Critical headway is being developed in the CNT field blend by this strategy even though nanotube tests still experience the ill effects of an absence of underlying control. This outlines how various parts of the development component stay badly comprehended. [75] The initial segment of this audit is committed to a synopsis of the overall foundation helpful for amateurs in the particular field. This foundation connects with the various carbon forerunners and their collaboration with various carbonaceous mixtures and their current circumstances. The subsequent segment gives a refreshed audit of the impact of the amalgamation boundaries upon the elements of CNT tests: breadths, metal/semiconductor proportion, chirality, and improper thickness. The third and last segment is given significant and open inquiries, like CNT nucleation’s chiral selectivity and instrument. Table 2 discusses the types of CVD processes based on the Activated manner.

<table>
<thead>
<tr>
<th>Chemical Vapor Deposition (CVD)</th>
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<tr>
<td><strong>Activated Manner</strong></td>
</tr>
<tr>
<td>Thermal CVD</td>
</tr>
<tr>
<td>Plasma Enhanced CVD (PECVD)</td>
</tr>
</tbody>
</table>
Laser-induced CVD
An original strategy for a local deposition is a single-step in nature or direct composition of the dainty metal, semiconductor, or separating insulator layers.

Microwave Plasma CVD (MWPECVD)
A continuous microwave source generates and maintains a highly reactive plasma composed of reacting chemicals and required catalysts.

Combustion CVD
A chemical method that deposits film coatings that are thin onto surfaces in the atmosphere.

Catalytic CVD (CCVD)
A complicated technique of forming thin coatings on a substrate surface via chemical interactions of gaseous gases.

**TABLE 2.** Types of CVD Processes based on the Activated manner [76]

---

**FIGURE 4** - CVD Setup in the primitive form. [78]

CVD, laser ablation, fire addition or synthesis by flame, high tension carbon monoxide, electrolysis, pyrolysis, and different cycles are utilized to make CNTs. However, due to its low cost and simplicity, the CVD approach is now the most extensively used method to produce CNTs. Figure 4 depicts the basic setup of the CVD process. This technology, first discovered in the late 1960s, has effectively produced carbon fibers and carbon nanofibers. CVD developed as a viable technology for large-scale CNT manufacturing and synthesis in the late twentieth century. [77] The catalyst is put on the substrate, thereby nucleated utilizing chemical synthesized etching (as ammonia) or thermal-based annealing in the CVD production of CNTs. After that, the supporting material which was prepared earlier is put into.......
a reactor that is tubular to grow. A combination of hydrocarbon gas (methane, acetylene, ethylene, and so forth) and a processed gas (argon, hydrogen, nitrogen) is then made to undergo a reaction inside a reaction chamber on top of the outer layer of metallic impetuses for a provided period (normally around fifteen minutes to an hour), and when the carbon antecedent deteriorates, CNTs develop on the impetus molecule or the catalyst portion in the reactor. Once the framework has been brought down to room temperature, the particles are gathered from the reactor dividers and backing surfaces. CCVD might be contrasted with other unmistakable CNT union cycles as far as impetus or catalyst molecule size. [78]

3.3 Significance in Carbon nanomaterial growth

In an upward direction, adjusted CNTs, particularly single-walled carbon nanotubes (SWNTs). What is more, double-fold wall CNTs (DWNTs) are a subject of colossal exploration exercises due to their prevalent morphological, thermal, and optical properties. Due to the extensive benefits of the upward arrangement over irregular direction, SWNT and DWNTs backwood contain extraordinary prospects as building blocks in superior execution and super fibers along with many other applications. It is normal for the rundown applications to be much lengthier if the width, radial thickness, divider count, and polarity are all managed. Trailblazer reports have exhibited the controlled development of top-notch upward adjusted SWNTs and DWNTs to uniform designs. [79]

Amongst the fundamental design boundaries of Carbon nanotubes, the divider count is of unique significance inferable from the way it is essential to control numerous significant characteristics. As a result, the creation of CNTs with uniform divider count is extremely required for explicit applications. As of late, the most well-known and effective development framework for upward direction adjusted Carbon nanotubes is the chemical vapor affidavit framework, which produces Carbon nanotubes following all around perceived vapor fluid strong (VLS) components. As per the VLS system, the impetus fills in like seed or then again format for CNT nucleation and development. Thus, impetus designing merits maximum consideration along with the particular development of V-CNT.

A basic principle of impetus design is obtaining impetus nanostructures with suitable thickness, shape, and interface qualities. The approaches that have been considered to achieve this goal are as follows: (I) Selecting appropriate compounds as metal impulse sustaining layers. Because of the solid Fe-Al2O3 connection, Al2O3 has been used as a typical solid support material, particularly for Ferrous impetuses. By better managing the shape and radial thickness value of Fe impetus Nanoparticles, the growth of an optional SiO2 supporting layer was recently discovered to advance the specific development of huge width in an upward direction adjusted V-SWNTs. (ii) Mega development aided by water. H2O was discovered to have two fundamental properties. One method is to draw the unreasonably undefined C over the impetus, which aids in maintaining the dynamic state of the Iron catalyst. Another is to prevent the growth and aging of the metallic impetus. (iii) Parallel or three times metallic impetuses are being created. The most often elaborate metals are Iron, Cobalt, and
Nickel.[79] The benefit of such impetuses stems from the combinatorial influence of the collaboration of numerous metallic pieces. For example, due to a more grounded link between Fe-Pt nanoparticles and the Aluminium trioxide layer than between Iron and Aluminium trioxide, Superfine and regular Synthesized Nanoparticles were formed worked with the development of V-SWNTs and upward adjusted DWNTs (V-DWNTs). The impetus piece of bimetallic impetuses was likewise displayed to impact the v-SWNTs exhibits’ stature. [80][81]

Enormous quality along with high virtue CNTs genuinely must require profoundly solid union methods. Understanding the impacting variables and control states of explicit carbon nanotube combinations is what we want. As of now, the planning system of MW-CNTs is full-grown also modern creation was acknowledged through the CVD-based process. The creation cost of SW-CNTs is already very elevated, and also the planning of plainly visible varieties of a few situated SW-CNTs has not been figured out.

CVD procedure involves isolating a carbon-based - atom that contains a gaseous substance constantly moving via the driving force nano - particle to deliver carbon-based particles, henceforth creating CNTs onto the outermost layer of the assisting catalyst or the required substrate. The mixed association permits the stimulant used to rot carbonated - based - source (commonly hydro - carbon - gas) at a satisfactorily elevated temperature-heat in a cylindrical or an adjusted reactor. The authentic setting of substance vapor testimony was followed to the nineteenth century. At around the end of the 19th century, French specialists saw carbon-like filling materials in tests, and for this, there was a cyanobacterial spread on hot porcelain [82]. This material was outlined by the joint effort of gases, including carbon-like substances with the external layer of fluid iron-metal, which was first declared in the late 19th century, but its fundamental nuances and mechanical-based characteristics are the consequence of late modification of electron-based microscopy. CVD might also be the first for filling materials and fiber-based CNT setup. Regardless, in the late 20th century, CVDs transformed into a technique for enormous scope assembling and association of CNTs [83].

Contrasted with the other two strategies, as far as crystallinity, albeit the crystal-like trait of CVD-based-developed MW - CNTs is truncated, also the crystal-like trait of CVD-developed SW - CNTs is near when compared to with by curve or laser-based system. Also, to note that CVD is regarded better when compared to bend and laser strategies as far as yield and virtue. CVD is the main suitable strategy for primary control or development boundary control.

Synthesis of Carbon Nanomaterials via CVD process is the most commonly used thin-film deposition method which enhances the growth of Carbon Nanomaterials. The CVD process used has a very low temperature requirement that makes the complete process cheaper, more efficient and more accessible for lab applications. The CVD approach provides for precise control of the shape and structure of the Carbon Nanomaterials generated, as well as the development of aligned nanotubes in a specified direction. Carbon Nanomaterials are deposited on a substrate using the CVD process, which uses hydrocarbon or other carbon-bearing precursors in the presence of a catalyst. In a CVD process, the temperature is usually
below 1200 °C. This method has the benefit of allowing the alignment, length, wall number, and diameter of CNTs to be controlled, resulting in Carbon Nanomaterials with the desired structure. In general, CVD is thought to be the most cost-effective method of producing Carbon Nanomaterials. [159]

Even though the development instrument of CNTs was very dubious, presently, there is noted to be more than one universally acknowledged component, which is to be summed up as follows. At this point, hydro-Carbon-based vapor is reached along with heated metal-based-nano-particles, firstly dissociated into carbon-based-atoms and hydrogen-based atoms. Elemental hydrogen is removed with the transporter or diminishing gas, and Carbon-based breaks up in the metal impetus. The decayed carbon particles accelerate and assume shape to frame CNTs when the temp drops the metal’s carbon dissolubility threshold. The breakdown of hydrocarbons is an exothermic interaction, while carbon precipitation is an endothermic cycle, and the warm tendency follows. The justification for the two development components is that when the impetus collaborates pitifully with the substrate, carbon disintegrated from the hydrocarbon diffuses from the metal impetus to the lower part of the metal impetus and accelerates between the substrate and the metal impetus, advancing the development of the entire metal impetus nanoparticles. The development comes to a halt when the metal molecule is completely covered by excess carbon, a phenomenon known as tip-growth [84]. The carbon stimulates without pressing up the metal particles when the urge unquestionably with the substrate; thus, it is driven to hasten from the metal’s maximum height, known as the “essential development model,” also known as root growth [85]. Figure 5 depicts the two CNT growth models – Root growth model and Tip growth model. The carbon source, impetus, reactor temperature, conceptual model pressure, stream pace of transporter gas, deposition time, reactor type, reactor computation, impetus assistance, interactive metal components in impetus, and other factors influence the final morphology and characteristics of CNTs during the blending process.
FIGURE 5. (a) Root growth and (b) Tip growth are depicted in a diagram of CNT growth mechanisms. [86] ("Figure reprinted with permission" from [86])

3.4 Synthesis of carbon-doped graphene nanoparticles using the CVD process
The arrangement of metal impetus nanoparticles is critical for the CVD combination of carbon-doped graphene nanoparticles. Nanoparticles should be shaped on the outer layer of a non-conductive material that is helpful for the development of those nanomaterials. The lattice material has a considerable influence on the production and character of carbon-doped graphene nanoparticles. The interface shape and particle size of the grid could significantly impact the arrangement of carbon nanotubes. Furthermore, the interfacial area of the impetus affects the development pace of the carbon-doped graphene nanoparticles. The primary goal of carbon-doped graphene nanoparticles [87]. It will incredibly advance the vast use of carbon-doped graphene nanoparticles in miniature nano electronic gadgets, sensors, astute useful materials, optical gadgets, and different fields.
Impetus type, impetus molecule shape, fluid type of the C origin, and response heat are the fundamental variables influencing the value and execution of carbon-doped graphene nanoparticles. Observing reasonable impetus kind and molecule dimensions, appropriate fluid type of the C origin, and response heat are essential for the enormous scope arrangement of great carbon-doped graphene nanoparticles. There is still a ton of space for investigation during the time spent carbon-doped graphene nanoparticles blended by the CVD technique. [84]

There are several studies on the CVD technique of synthesis. Several aspects have been taken into mind to synthesize superior quality and quantity. Simple setups, which can be made in any normal laboratory, were used to regulate these parameters. This approach has much potential for large-scale manufacturing of SWNTs, MWNTs, and Nanofibers. Even though numerous experimental data on the development process of carbon nanomaterials have been acquired, there are many variables to examine before thorough knowledge can be created. The present investigation may lead to a better explanation of the CNMS-growth mechanism and improved optimization of the synthetic process [88]

The substrate is critical in the Chemical Vapor Deposition production of carbon-doped nanostructures. The most extensively used CNT substrates are Si, MgO, and Al. Several other substrates have been used successfully as supports to generate carbon-doped graphene nanoparticles in the last decade. The substrate’s surface shape and crystalline steps affect carbon-doped graphene nanoparticles’ production, quality, and orientation. Catalysts for carbon-doped graphene nanoparticles development require a proper substrate material to ensure CNT quality and yield. The substrate’s material, surface shape, and textural qualities [89].

4. Electrochemical Applications: Carbon Nanomaterials as Prerequisites
Carbon nanotubes have aroused curiosity due to their unusual shape, nanometer scale, new physio-chemical features, and, most importantly, their versatility. CNTs can be seen as composite graphene sheets (SP2 carbon arranged with a honeycomb type of lattice). CNTs are categorized into Multi-walled CNTs (MWNTs) and also Single-walled CNTs (SWNTs). MWNTs are straight and closed graphite tubes with multiple layers of graphite sheet defining a hole usually 2 to 25 nm wide and spaced 0.34 nanometer. SWNT is made of a single sheet of crystalline-graphite formed into a cylinder-like shape with a 1-2 nanometer diameter. CNTs can act as metals or semiconductors as per their structure, largely determined by their width and durability.

Electrochemical Performance in Graphite, amorphous carbon, and diamond were regarded as the most extensively used allotropes of carbon-atom among the numerous allotropes. Furthermore, there are a variety of carbon allotropes with an extensive variety of dimensions in the lab for various applications, especially for powering solar cells. The helicity of the graphite ring arrangement and the diameter of the CNTs determine whether the CNTs are semiconducting or metallic. Molecular metallic wires with distinct optical, electrical, mechanical, and magnetic characteristics are created by combining various CNTs. CNTs might be used in gas and electrochemical storage, SEM tips, single molecular transistors, sensors, and electron field emitting flat panel displays because of their unique features. [90] Additionally, using Graphene as a reinforcement improves the optical, mechanical, and electrical characteristics. Table 3 below shows the good electrochemical properties that Carbon Nanotubes possess.

<table>
<thead>
<tr>
<th>Form of Carbon</th>
<th>Hybridization</th>
<th>Electron mobility (cm²/Vs)</th>
<th>Young’s Modulus (TPa)</th>
<th>Thermal conductivity (W/m-K)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNT</td>
<td>sp²</td>
<td>1,20,000</td>
<td>1.033-1.042</td>
<td>6600</td>
<td>[91, 92, 93]</td>
</tr>
<tr>
<td>Graphite</td>
<td>sp²</td>
<td>1.5*104</td>
<td>0.795</td>
<td>2200</td>
<td>[94, 95, 96]</td>
</tr>
</tbody>
</table>
| Graphene       | sp²           | 2,00,000                   | 1.06                  | 4840-5500                   | [97, 98, 99]|<br>**Diamond**
|                | sp³           | 1,800                      | 1220                  | 25                          | -          |
|                | sp²           | 0.4-1                      | 53-69                 | -                           | [100, 101]|

The applications of carbon nano materials in energy storage applications are discussed below:
4.1 Carbon nanotubes for energy storage

The deployment of practical alternative energy systems is becoming increasingly vital as fossil fuel resources become scarce. Fuel cells are likable sources. CNTs were extensively studied for hydrogen storage stimulants and essential parts. CNTs are a popular choice for electrodes included in the capacitors and batteries due to their inherent properties. CNTs possess a high-level reversible capacity, making them ideal for adapting lithium-ion-based batteries-cell and a diversity of fuel cell part-components. CNTs can also be utilized in current-based collector devices and gas-based-diffusion layers due to their high-level electrical conductivity. CNT and Graphene are excellent electrodes for the catalyst assist in fuel-based cells due to their highly integrated surface area and thermal heat conductivity.[102]

Carbon is a significant element, and it is used in living beings and modern technology in both sophisticated and elemental forms. Carbon comes in various allotropic forms and morphology-based textures (e.g., Graphene-based crystals, diamonds, lonsdaleite, Bucky-ball, and amorphous-based-carbon) (nano—tube, nano-wire, and Graphene-based - matter). Properties in electronics and other adaptations are tailored to the textured-like behavior of the allotrope of desired attributes. Also, since the initial discovery of graphite and diamond in 1779, their inventive applications have continued to increase till now. Utilizing the pros of these Carbon-based- morphologies, the path toward invention-and-also research had proceeded with rapid pace, and over two centuries later, in 1992, MWCNTs and SWCNTs were reported for the first time [103]. It is important to note that graphite and carbon nanotubes have a lot of distinct properties and characteristics which make them suitable for energy storing device applications. It is important to remember that CNTs have been foreseen to significantly impact various aspects of science and technology due to their exceptional capabilities and structural attributes [104,105,106]. SWCNTs acquire tensile stress of 60 Giga Pascal and high electronic-based conductivity [107][108]. CNTs are utilized in intensity-based- storage and change related arrangements such as alkali - based - metal - ion battery-cells [109], fuel-based -cells [110], nano-based -electrical systems [111], super-capacitors [112], and hydrogen-based-storage devices [113], pertaining to their potential based practical applications in electrochemical based biosensors [114][115], field ray emission materials [116], catalyst-materials [117], and electrical based devices [118]. CNTs' extremely high electrical conductivity can be used as an additive in composite electrodes to help trigger poor conductor types of electrode materials and optimize them to be electro-chemically agile. Peanut-shell could also be used as an exceptional choice of biowaste material to produce substances that have added value like graphene for its application in systems for storage of energy. [166]

4.2 Carbon Nanotubes as Electrochemical Biosensors

Carbon-doped graphene nanomaterials-based electrodes as electrochemical biosensors have promising significance due to its remarkably high mechanical strength, conductivity, biocompatibility, large detection area, abundant catalytic sites and biosafety. [164] CNTs
have been extensively analyzed to determine the biomolecular electrochemical potential of various electro-biomedical applications. CNTs can have their structures designed to match their strength as biosensors. Antibodies and enzymes are utilized to modify the characteristics of CNTs in electrochemical biosensors. Peptides and nucleic acids can modify the features of CNTs as sensory biosensors as they have the inner ability to detect bioelements or biomolecules. To fix the surface of the CNTs in a certain visual way, biomolecules are attached to the top. For this purpose, many biomolecules with bio-enzymes, bio-proteins, and some nucleic acids are widely utilized in CNT-type electrochemical biosensors.

Usage of metallic nanoparticles to produce biosensors that are extremely sensitive is promising because of their biocompatibility and high activity. Attainment of electron transfer directly between the electrode surface and redox enzymes is highly crucial in the making of these biosensing devices. The utilization of nanostructured materials like CNTs, quantum dots and so on in the design of these biosensors is one of the latest developments in achieving the required electron transfer directly. The metallic nanoparticles on the surface of the electrode can facilitate the electron transfer process and work as nanoelectrode ensemble. Conjugates of redox enzyme-Au nanoparticle can be used based on different interactions for the production of these electrochemical biosensors. The functionalized CNTs with redox relay have been effectively employed for NAD(P)H/NADH sensing and biosensor manufacturing.

CNTs are considered nano-probes of the ongoing generation, as they have distinct structure-related, mechanics-related, electronics-related, and optics-related properties. They were suitable for biosensor applications due to their wide format profile, high-level efficiency, high-level chemical stability, reactivity sensitiveness, and fast electron transfer rate. The immobility of biomolecules in the environment of CNT-based biosensors is its basic feature. This basic feature improves the recognition and process of signal transmission. Based on their targeted perceptions and transmission methods, the classification of these biosensors is made into electrochemical-based biosensors and electronic CNT and optical biosensors. Figure 6 depicts different pH responses that provide various kinds of biosensors, according to the development method for electrochemical biosensors based on pH sensitivity behavior. With the right combination of electrical and electronic biosensors, CNTs are very promising as they increase electron transfer. Figure 6 depicts the design of CNT-based biosensors, both electronic and electrochemical.
FIGURE 6. CNT biosensors, both electrochemical and electronic (A) A typical enzyme-based electrochemical biosensor design. (B) A glucose oxidase electrode with a SWNT electrical contact. (C) A label-free amperometric biosensor for PSA detection is shown schematically. (D) A microfluidic chip based on CNT electrodes is depicted schematically. [125]

4.3 Carbon Nanomaterials in power fuel cells

Fuel cells have a nature of low pollutant emission and high energy conversion efficiency and are considered a promising technique that can be utilized to resolve forthcoming environmental problems and energy crises. Carbon nanotube (CNT) utilized as the catalysis support is vital in fuel cell applications.

Both SWCNTs and MWCNTs can permit electrons to flow, store hydrogen, or intensify the activity of the catalyst. [126] Due to this, while carrying out fuel cell research, carbon nanotubes (CNTs) synthesized by CVD can be added to the catalyst mixture at the anode to enhance the effectiveness of the catalytic reactions occurring inside the fuel cell. Nitrogen-doped carbon nanotubes have been found to diminish the oxygen at the cathode inside the fuel cells. Using vertical alignment, CVD synthesizes carbon nanotubes can also decrease the oxygen level in the alkaline solution more efficiently than platinum alone. [127] CNTs synthesized by CVD as an electrode in SAFC often enhance the linking occurring between the current collector and the catalyst nanoparticles (be it platinum or any other catalyst). Moreover, multi-walled Carbon nanotubes (MW-CNTs) intensify the ratio of volume and the area of the surface of the anode. [128] The mixture of SW-CNTs and MW-CNTs...
CNTs used as platinum, or any other catalyst support can improve the quality of activities occurring at the cathode and enhance the mass transportation in the layer of the catalyst.

4.4 Carbon Nanomaterials influence and Electrochemical performance on Symmetrical and asymmetrical supercapacitors

Carbon nanoparticles are a strong contender for substituting activated carbon as the electrode in symmetrical and asymmetrical supercapacitor high-performance. They have good electrical characteristics, a wide surface area, high electrolyte accessibility, and high mesoporosity. Alternatively, aggregation of CNTs and graphene-based materials reduces area, thereby worsening the device’s performance. Due to this, producing carbon nano matter with a high charge capacity at a cheap cost is extremely necessary.

Electrodes built on vertically aligned CNTs with tips that are opened along with sheets of Graphene with adjustable edge functions and thickness stacking interactions (in addition to 3D pillared graphene carbon nanotube networks) can be utilized to make supercapacitors have high performance. [129] Coating these so-formed modified Carbon nanotubes (CNTs) with metal oxide and conductive polymers to induce pseudo-capacitance can enhance their performance and make them even better. However, aggregation tends to affect a reduction of surface area, so further improving the performance of devices based on CNMs remains a problem.

To prevent this aggregation, CNMs with diverse 3-dimensional structures (for example, 3D pillared vertically aligned Carbon nanotube/graphene (VA-CNT/graphene) networks, graphene foams, and Carbon nanotube arrays) have been constructed, in addition to a 2D graphene sheet placed onto a crumpled structure. [130] The aggregation of carbon nanotubes (CNTs) and graphene materials causes a reduction of surface area, resulting in poor device performance. Another barrier for carbon nanomaterials to increase their practical application in supercapacitors is that these materials are expensive compared to commercially activated and mesoporous carbon.

Creating clean and renewable energy systems and improving energy storage technologies is critical since CO₂ emissions and global energy consumption grow dramatically. To solve this problem, nanotechnology has opened innovative horizons in engineering and materials science by developing novel materials and technologies for energy storage and conversion. CNMs have also proven to be useful in sophisticated energy storage applications. Coating them with metal oxide and conductive polymers to induce pseudo-capacitance can improve their performance. However, significantly improving the performance of carbon nanomaterial-based supercapacitors remains a challenge. On the one hand, aggregation of graphene materials and CNTs causes a reduction of surface area, resulting in deficient performance of the device. To prevent aggregation, CNMs with diverse 3-dimensional structures have been constructed and a 2-dimensional graphene sheet placed onto a wrinkled structure. On the other hand, the comparatively expensive cost of carbon nanoparticles compared to commercially activated carbon and mesoporous carbon is another barrier to
scaling up for use in supercapacitors. As a result, developing carbon nanomaterials having large charge capacity at a reasonable cost is very desirable.[131] Graphene and other 2-dimensional nanosheets with many crystallite layers or atoms are being widely studied as a novel class of nanoscale constituents. A 2-dimensional structure having a very small thickness constantly has a lot of surface area and unique features. The use of 2D nanosheet materials in the Design of asymmetric supercapacitors can significantly reduce ion diffusion length, enhance electrolyte contact area, and improve active material usage.[132]

4.5 Carbon Nanomaterials to power Dye-sensitized solar cells (DSSCs)

CNTs, when applied to carbon electrodes, have been shown to enhance the DSSCs performance. The general schematic diagram for a DSSC is shown in Figure 7. These Carbon nanotubes (CNTs) with a high electron affinity can be deployed as electron collectors, enhancing carrier mobility (DSSCs). Using carbon nanotubes as counter carbon electrodes might pave the way for non-platinum-based electro chemicals in solar systems.

![FIGURE 7. DSSC General Schematic diagram](https://mc04.manuscriptcentral.com/jss-ecs)

According to the results of the cyclic voltammetry investigation, the counter electrodes made of mesoporous Carbon and Multi-walled Carbon Nanotube have a high current density, suggesting strong electrochemical activity, and both constituents have efficiencies equivalent to platinum. [134] As a result, carbon dye with a big surface area and small size generated
from improper oxidation of the coal tar appears to be a cheap cost countering substitute electrode for DSSC. Table 4 mentions the Photovoltaic parameters of DSSCs by using a variety of carbon counter electrodes.

**TABLE 4.** Photovoltaic parameters of DSSCs by using a variety of carbon counter electrodes.

<table>
<thead>
<tr>
<th>Form of Carbon</th>
<th>J&lt;sub&gt;SC&lt;/sub&gt; (mA/cm&lt;sup&gt;2&lt;/sup&gt;)</th>
<th>Efficiency (%)</th>
<th>Filling Factor</th>
<th>V&lt;sub&gt;oc&lt;/sub&gt; (V)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>MWCNT</td>
<td>15.64</td>
<td>9.02</td>
<td>0.62</td>
<td>0.78</td>
<td>[134]</td>
</tr>
<tr>
<td>Nanocarbon</td>
<td>-</td>
<td>6.73</td>
<td>0.62</td>
<td>0.74</td>
<td>[135]</td>
</tr>
<tr>
<td>Carbon Black</td>
<td>16.8</td>
<td>9.1</td>
<td>0.68</td>
<td>0.78</td>
<td>[136]</td>
</tr>
<tr>
<td>Graphene</td>
<td>7.7</td>
<td>2.825</td>
<td>0.54</td>
<td>0.68</td>
<td>[137]</td>
</tr>
<tr>
<td>Activated Carbon Nanofiber</td>
<td>15.4</td>
<td>7.21</td>
<td>0.64</td>
<td>0.73</td>
<td>[138]</td>
</tr>
<tr>
<td>Mesoporous Carbon</td>
<td>15.5</td>
<td>6.18</td>
<td>0.65</td>
<td>0.6</td>
<td>[139]</td>
</tr>
<tr>
<td>Graphene nanoplatelets</td>
<td>11</td>
<td>4.38</td>
<td>0.6</td>
<td>0.67</td>
<td>[140]</td>
</tr>
</tbody>
</table>

DSSCs with a light-scattering layer made of a multi-walled carbon nanotube (MWCNT)–TiO2 nanocomposite is commonly used. Electrochemical impedance spectroscopy (EIS) was utilized to calculate resistance in the DSSC. EIS results show that increasing MWCNT concentration up to 3 wt% reduces charge resistance, improving photovoltaic performance. The DSSC showed a 100 percent boost in converting solar energy to electric energy compared to a nanocrystalline TiO2 single-layer cell [141]. Table 5 discusses the Photovoltaic parameters of Carbon Nanotube and various other counter electrodes.
<table>
<thead>
<tr>
<th>Type of Counter electrodes</th>
<th>Method of Preparation</th>
<th>About the counter electrode</th>
<th>Applications</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Nanotubes</td>
<td>They can be prepared by numerous methods like laser ablation, CVD, arc discharge evaporation, plasma-based synthesis, etc.</td>
<td>The DSSCs made with CNTs showed great stability even at angles up to 90. The overall efficiency measured can be further enhanced by adding a conventional metallic wire-like copper and silver.</td>
<td>Utilizing counter electrodes made of CNTs can significantly enhance the performance of various devices ranging from batteries and supercapacitors to desalination systems of water.</td>
<td>[142]</td>
</tr>
<tr>
<td>Carbon Black</td>
<td>It is typically prepared by the improper combustion of vegetable oil, coal tar, and heavy petroleum products.</td>
<td>Carbon black has a large surface area due to which they have enhanced catalytic activity. Moreover, photovoltaic parameters such as efficiency and fill factor are increased as they depend on the thickness and thickness of Carbon Black.</td>
<td>Carbon black is extensively used as a counter electrode material for electroanalytical chemistry purposes due to its high conductivity and superficial area. Mainly used as electrode in Lead Acid Batteries.</td>
<td>[143, 160]</td>
</tr>
<tr>
<td>Mesoporous Carbon</td>
<td>It is mostly prepared by organizing a carbon precursor and a surfactant.</td>
<td>These materials have a large surface area and a thin pore size distribution, due to which their performance in a DSSC is more enhanced than activated carbon.</td>
<td>Mesoporous carbon can be utilized in storage devices for storing energy and can also act as a support for catalysts.</td>
<td>[144, 161]</td>
</tr>
</tbody>
</table>
Graphene/TiO$_2$ composites are prepared by mixing TiO$_2$ with graphene oxide. The graphene oxide is converted to Graphene by UV radiation or chemical reductants. The composite produced is then calcined at 450 °C.

Two-dimensional graphene sheets exhibit higher electrical conductivity and have a higher surface area than the 1-dimensional CNTs. This high electrical conductivity assists in the quicker transmission of electrons and reduces recombination.

TiO$_2$/graphene composites are mainly used as electrodes for supercapacitors and dye-synthesized solar cells. Another major application is its usage in photocatalytic hydrogen evolution.

| Table 5: Photovoltaic parameters of Carbon Nanotube along with various other counter electrodes (Carbon Black, Mesoporous Carbon and Graphene/TiO$_2$) and their applications |

Carbon nanotubes have amazing electrical, thermal, and mechanical capabilities, allowing for intriguing DSSC applications. The advancement of CNTs, Graphene, and their nanocomposites as potential replacements for counter electrodes and transparent conductive oxide (TCO) layers is discussed. By increasing electron transport and light absorption, the performance of absorbing layers in functioning photo anodes can be increased [147]. Figure 8 depicts Important Electrochemical applications using Carbon Nanotubes as prerequisites.
FIGURE 8. Important Electrochemical applications using Carbon Nanotubes as prerequisites

6. Summary

Carbon nanotubes (CNT) have been widely researched using chemical vapor deposition (CVD). CNTs have been discovered to grow up to several centimetres in length and with unusual aspect ratios. The most prevalent carbon sources employed for CVD investigation of CNT development were methane, acetylene, ethane, and ethanol. CNTs are effective model systems for gaining access to low-dimensional physics.

The electrocatalytic activity of Graphene is increased by doping it with most of the elements. Chemists all around the globe utilize boron and nitrogen dopants because they have the same C-atom sizes and exhibit good graphene conduction. Dopamine, uric and ascorbic acid will be studied here on the interface of doped nanosheets.

Here we talked about carbon-doped graphene nanomaterials. Doping Graphene with most of the elements makes its electrocatalytic activity increase. So, Graphene doped with carbon results in a significant improvement in its properties. We also looked at various stabilizing agents for carbon-doped graphene nanomaterials. Some of them are Benzimidazole (BI), which reduces the responsiveness of the Copper-etching mixture by producing a stable complex, CoFe$_2$O$_4$, which has excellent photocatalytic activity and the chemical inertness and conductivity of carbon compounds, Molybdenum disulphide, which Enhances electrocatalytic activity for the hydrogen evolution process, Sodium dodecyl sulphate (SDS) which contributes to considerable conductivity increase of the ECAs at visibly less content of filler and Gelatin which leads to Increased fluorescence activity.

CVD is a vacuum-based deposition procedure adapted to generate high-quality, high-performance materials. Although the development instrument of CNTs is dubious, there are presently 2 universally acknowledged components, which can be summarized as discussed henceforth. When a vapor of hydrocarbon is encountered with warmed nanomaterials, it is first decomposed into H$_2$, and C. Carbon breaks up in the metallic impetus as H$_2$ escapes with the moving carrier gas or decreasing gas. Numerous boundaries influence the final surface characteristics and characteristics of CNTs during the blend, such as the source of carbon, initiative, reactor heat, framework stress, stream pace of transporter gas, dynamic metallic objects in impetus, and so on.

CBN has been studied extensively in the last 2 decades as one of the most frequently used nanomaterials. CBNs have been widely used in various fields due to their natural structure, visual, electrochemical, and electronic capabilities. CBNs have also focused on the bio-electro-chemical engineering field during the last decade due to their varied topologies, dimensions, and form. Given the presence of both inorganic semiconducting structures and – compounds, CBNs proved promising. As a result, it can successfully interact with biomolecules while also responding to light. CBN-based nanoparticles may be employed to
improve upcoming electrochemical bio-applications by combining such properties in a single enterprise. Several chemical-based reunification procedures have been established and effectively applied in electrochemical applications such as the delivery of drugs, biomedical engineering, biomolecule sensing, and treatment for cancer due to their toxic effects on the biosphere. This review article addresses some latest progress in using CBNs in electrochemical-based characteristics and applications. In addition, some of the most important recent properties of CBNs and their use in electrochemical applications are discussed in this work. Because CBNs still include toxins, more research is needed to evaluate their toxicity and pharma-co-kinetiños.

From our research, we have also found out that Carbon Nanomaterials synthesized by Chemical Vapor Deposition (CVD) enhance the performance of Symmetrical and Asymmetrical super-capacitors due to their wide area of surface and improved electrical properties. They also have wide application to power various fuel cells as they can permit the flow of electrons and intensity of the catalyst’s activity twofold. A comparison of Carbon Nanotube as a counter electrode with various other counter electrodes was studied, and it has promising photovoltaic parameters. Due to this, it can potentially power Solar cells in the future.

In summary, this review highlights the significance of using Chemical Vapor Deposition synthesized Carbon-doped graphene Nanomaterials and their chemical structures, stability, and electrochemical applications.

7. Conclusions & Future Directions

Carbon or other heteroatom doped graphene has emerged as an important study sector that is currently experiencing rapid developments, evidenced by the avalanche of recent publications. The emergence of these freshly doped carbon compounds has sparked much interest. It has received huge attention for its usage in many characteristics and applications. One should note that carbon doping on Graphene is a comparatively recent subject, with huge future potential. Overall, available research suggests that doped Graphene is a feasible material as catalyst support as well as an isolated metal-free photocatalyst, with the ability to address challenges such as inadequate conductivity, visible-light sensitivity, and catalytic activity. Nonetheless, even though significant work has been expended in its advancement, several obstacles remain that must be solved [148-151]. To realize the significance of energy and environmental applications, new carbon nanostructures must be discovered using sustainable and low-cost methods. The development of a reliable and scalable transfer mechanism for graphene growth on Cu (or any other metallic substrate) is still a difficult problem. CNTs need to be synthesized in longer lengths, and more advanced techniques are needed to align and uniformly distribute them.

Future graphene transfer technologies will continue to focus on low cost, scalability, and simplicity. More emphasis should be placed on studies including numerical simulations and
modeling methodologies to address these challenges. Furthermore, a rigorous side-by-side comparison of different dopants should be undertaken to establish a clear association between distinct dopants and their unique qualities. Detailed knowledge of the topic can thus assist future work on controlled doping and systematic tailoring of Graphene to fit a certain performance profile flexibly. We also looked at carbon nanotubes as biosensors, carbon nanotubes for drug delivery, CNTs for cancer therapy, CNTs for energy storage, carbon nanotubes as conductive plastics, carbon nanomaterials to power fuel cells, carbon nanomaterials’ influence on symmetrical and asymmetrical supercapacitors, and carbon nanomaterials to power dye-synthesized solar cells and Significance of CVD to synthesize Carbon Nanomaterials. A significant amount of study is required on all these issues, as there are just a few published papers on these topics so far [152-154]. The ability to synthesis carbon nanotubes with excellent selectivity and quality under moderate circumstances makes them more enticing for usage in other applications where the materials’ extraordinary physical and chemical characteristics would be beneficial.

References


