Chapter

Advanced Carbon Materials: Base of 21st Century Scientific Innovations in Chemical, Polymer, Sensing and Energy Engineering

Muhammad Ikram, Ali Raza, Khurram Shahzad, Ali Haider, Junaid Haider, Abdullah Khan Durrani, Asim Hassan Rizvi, Asghari Maqsood and Mujtaba Ikram

Abstract

Advance carbon material that includes graphene, fullerenes, hierarchical carbon, and CNTs are referred to as strength of revolution and advancement in the era of material science and technology. In general, 20th century corresponds to plastic meanwhile 21st century will be named as "Century of Graphene" owing to its exceptional physical properties. Graphene is now well-known and prominent 2D carbon allotrope that is considered as multipurpose material in comparison with any material discovered on earth. One of the interesting properties of graphene is strongest and lightest material that enables it to conduct electricity and heat as compared to any other material. Such features permit it to utilize in numerous applications including biosensors, electronic industry, environmental remediation, drug delivery, energy storage, and production as well. Owing to these capabilities, it can be stated that graphene can be utilized to improve effectiveness and performance of existing substances and materials. In the future, conjugation of graphene with other 2D material will be devolved to produce further remarkable compounds that make it appropriate for an extensive variety of applications. This chapter grants the utilization and applications of advanced carbons materials in chemical, polymer, sensing and energy enegineering.

Keywords: polymer composites, nano coatings, lubricants, nanofluids, biosensors, fuel cells, supercapacitors

1. Introduction

Carbon has been distinguished into variety of forms as amorphous carbon, diamond, and graphite. Among these, the well-recognized allotropes of carbon since ancient times are diamond and graphite. The third kind of carbon named fullerene was discovered by Kroto et al. in 1985 whereas; carbon nanotubes (CNTs) were discovered by Iijima in 1991 that leads to gain a significant role in the field of science and technology. Accordingly, only three kinds of carbon allotropes were identified and well-known in the carbon family are first, diamond and graphite

(3D) secondly, CNTs (1D) and thirdly, fullerenes (0D). Later, in 1991 it was realized that CNTs were fabricated by rolling of 2D graphene single sheet that was extracted from 3D graphitic material [1–3]. Furthermore, isolation of graphene was somewhat struggling and indefinable concerning any effort corresponds to experimental research until 2004. Graphene is an elementary structural element of CNTs, fullerenes, and graphite that are named as allotropes of carbon family. Fullerene is entitled as buckyball as it is composed of carbon sheets in the arrangement of spherical profile. In comparison with fullerene, CNTs acquire tubular form. For more than two decades, CNTs and fullerene-based martial expose extensive applications in the varied portion of the research that involve biosensors, super-capacitors, electrochemical sensors, electronics, fuel cells, batteries, and medicinal applications. Presently, graphene is entitled as "Rising Star Candidate" after its effective production from scotch tape process by utilizing voluntarily accessible graphite by Andre Geim and his coworkers in 2004. Single-layer sheets of graphene consist of carbon atom that is sp^2 bonded and acquires honeycomb-like lattice which is densely packed. As an active material, remarkable properties of graphene that include tunable bandgap, high specific surface area, superior thermal, electrical stability and conductivity, and more importantly Hall effect (at room temperature) provides suitable platform for its utilization in the production of several composites materials [4]. Struggles were devoted to reviewing the structure and preparation of graphene its properties, possible applications, and finally composite material [5–8]. At present, owing to possess remarkable properties, graphene is shortlisted as the most widespread material that can be employed for several devices and applications. This chapter grants the utilization and applications of graphene in various approaches, the synthesis routes, and numerous exceptional properties.

2. Application

Previously, graphene has illustrated promising impression to various information communication technology areas that sorts from a high-performance application (top-end) in ultrafast information processing (i.e. THz) to consumer applications by means of flexible electronic structures. An authentic property of graphene is verified by the increment in the score of chip makers now energetic in research based on graphene. Prominently, graphene is reflected as the emerging candidate that can be utilized for post-Si-electronics. Most auspicious applications of graphene contain light processing, sensors, electronics, plasmonics, energy storage, meta-materials, generators, etc. Besides, graphene is utilized to enhance various industrial and medical processes. The overview for the applications of graphene is displayed in **Figure 1**.

2.1 Polymer composites

Biphasic materials are considered as polymeric composites, which are attained by dispersing one phase into another controllably. Modified graphene may be dispersed into polymer-matrix to become reinforcing-filler to increase optimally physiochemical properties [10]. Firstly, Stankovich et al. presented phenyl isocyanated graphene acting as nanofiller during the synthesis of polystyrene (PS)/graphene matrix [11]. It was observed that only 2.4 vol% increments belonging to surface-modified graphitic compound filled desired composites, caused by enlarged surface area graphitic composite. The electrical conductivity attained percolation threshold by incorporating about ~0.1 vol% graphene as illustrated **Figure 2**. Reports offered by Eda et al.

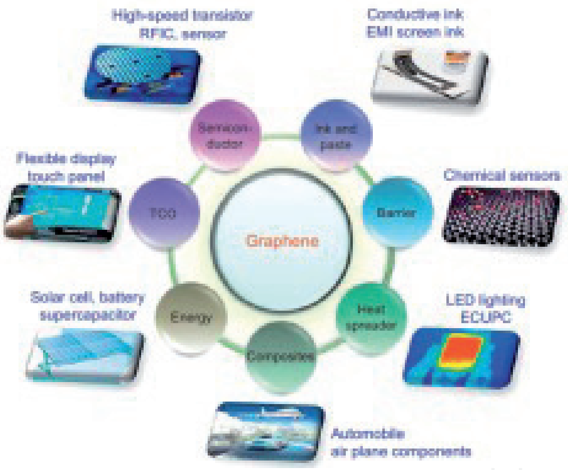

Figure 1.
Overview of applications of advanced carbon material (graphene) [9].

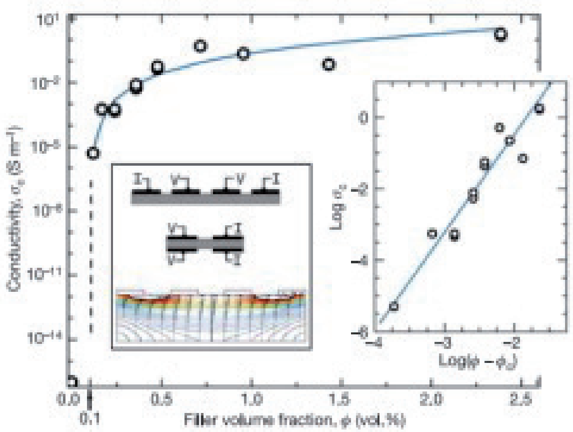

Figure 2.
Electrical conductivity of phenyl isocyanate modified. graphene filled polystyrene composites [11].

exhibited functionalized graphitic filled PS-composites showing the same electrical properties as that of monolayer rGO nanosheets [12]. Whereas PS-composites are being explored p-type semiconducting nature at high temperatures.

Kuila et al. reported that dodecyl-amine (DA) along with octadecy-amine (ODA) functionalized graphitic filler during synthesis of linear-low-density polyethylene (LDPE), while ethylene-vinyl-acetate (EVA) composites were obtained respectively [13–16]. Modified-graphene was well dispersed in LLDPE as well as EVA matrix during hydrophobic-interaction with alkyl-chains of polymer matrix along with modifier. As far as tensile strength is concerned, it acts with storage-modulus collectively to composites as they are increased with surface-modified graphene optimally to a certain limit, thereby decreasing with additional fillers. Epoxy graphitic composites have been detailed in investigation processes [17–19]. It has been keenly observed that little increment of surface-modified graphitic material increasingly enhances mechanical as well as thermal stability as compared with neat epoxy. This corresponds to reasonable surface area along with superior mechanical-strength attributing to graphene composite. Some other usable polymers for graphitic-composite preparation are known as polyvinyl-alcohol, crystal-polymers, polypropylene, polypyrrole, polymethyl methacrylate chitosan, cellulose, polycarbonate, polyethylene terephthalate, and polyvinyl chloride [20–25]. Graphitic-polymers offer potential applications towards automobiles, air-craft industry, turbine blades, bony structures, and tissue culture implantations [26–30].

2.2 Nano coatings: antimicrobials and microelectronics

Carbon nanotubes show a promising multifunctional nature material in coating fabrication. Metal decorated CNTs are considered as hybrid-systems that may be prepared by using those CNTs having carboxyl-groups, binding transition metal ions such as Ag^+ and Cu^{2+}. These aforesaid ions contribute a large part to their superior antimicrobial activity to destroy bacterial as well as fungus microbes along with less cross-resistance towards antibiotics (see **Figure 3a** and **b**) [31]. MWCNTs with paint materials successfully reduce biofouling-ship-hulls owing to discourage embodied algae with barnacles [32]. Consequently, they are referred to as alternatives for environmentally polluted biocide type paints. Anticorrosion-coatings include CNTs for metals for enhancement of coating-stiffness and strengthen them to make an electric pathway to create cathodic protection.

Widespread progress has been made for fabrication of CNTs that are based on flexible and transparent conductive thin films [33–35] proving alternative material of indium tin oxide. The main issue concerning ITO is its expensive nature owing to shortage of indium. However immense need for displays, touchscreens and photovoltaic provide stimulus. Moreover, CNTs flexibility raise the transparency of conductors showing a major advantage over ITO coatings towards flexible displays. Additionally, transparent CNTs conductors are deposited from solutions such as slot-die coating as well as ultrasonic spraying along with cost-effective non-lithographic approaches likewise micro-plotting. The latest effort has been made for fabrication of CNTs films showing 90% transparency with 100-ohm resistivity per square as is clear from **Figure 4**. Surface resistivity so much appeared is considerably suitable for promising applications. However, substantially it is better than equally transparent and optimal doping with ITO coatings [36]. Widespread applications have exhibiting requirements relevant to CNTs thin-film-heaters and are substantially used for defrosting automobile-windows as well as sidewalks. Aforesaid all types of coatings are widely used on an industrial level.

Recently, CNTs films are transparent; however, stretchable flexible may often tailor in the form of shapes and sizes. They are freestanding and are placed on rigid or flexible insulated surfaces. A piece of carbon nanotube CNTs thin films may explore magnet-free-loudspeaker. It may simply show through applying an audio-frequency-current passing through it depicted in **Figure 5**. CNTs film loudspeaker produces sound waves with high-frequency range, a wide range of sound pressure-level along with low harmonic-distortion [37]. These CNTs thin films behave like transistors, proving more attractive towards driving organic light-emitting-diode

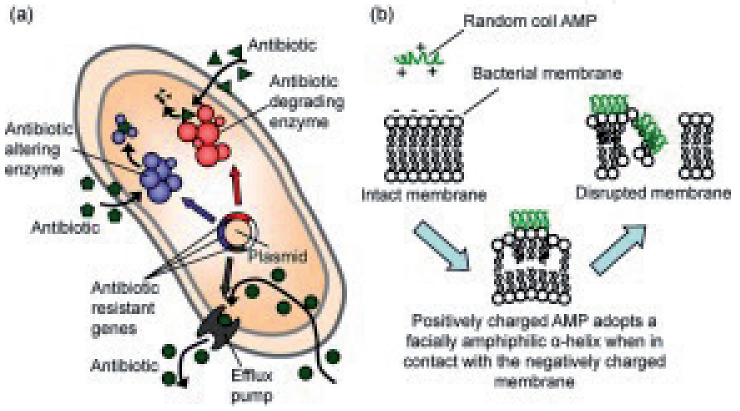

Figure 3.
*Comparison in functional mechanism between small molecular antibiotics and macromolecular antimicrobials **(a)** mechanisms of antibiotic resistance in bacteria, **(b)** mechanism of membrane-active antimicrobial peptides.*

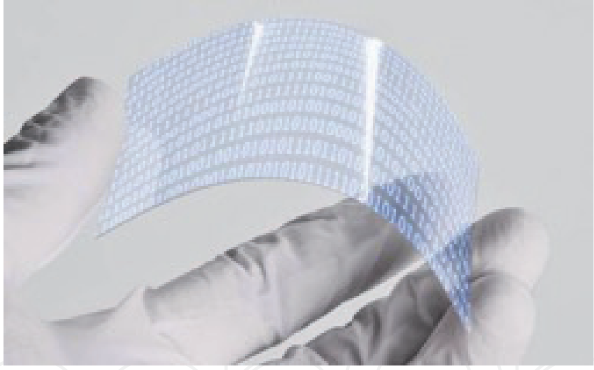

Figure 4.
Carbon nanotubes flexible transparent conducting film ((image courtesy Plasticstar material news).

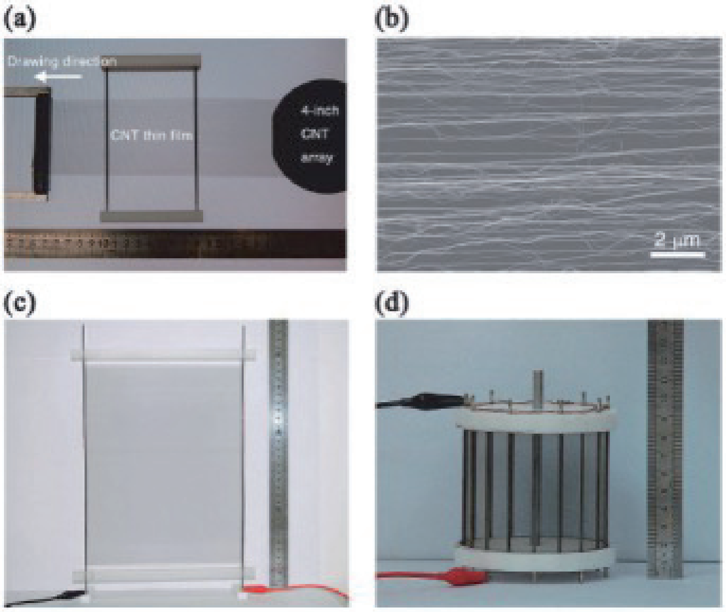

Figure 5.
Carbon nanotube thin film loudspeakers ***(a)*** *the CNT thin film was pulled out from a super aligned CNT array grown on a 4 in. Silicon wafer and put on two electrodes of a frame to make a loudspeaker.* ***(b)*** *SEM image of the CNT thin film showing that the CNTs are aligned in the drawing direction.* ***(c)*** *A4 paper size CNT thin film loudspeaker.* ***(d)*** *the cylindrical cage shape CNT thin film loudspeaker can emit sounds to all directions, diameter 9 cm, height 8.5 cm [39].*

screen display. Because of this reason, they have explored higher-mobility as compared with amorphous silicon, depositable by low-temperature, and vacuum-free approaches. Today flexible CNTs -TFTs having mobility 35 cm^2 V^{-1} s^{-1}, whereas an on/off ratio of 6 × 10^6 has been demonstrated in **Figure 5a, d** [38].

2.3 Lubricants

Applications corresponding to surface-functionalized-graphene show additive counterpart in lubricant oil refinery owing to progressing research field. Extremely large mechanical-flexibility, fine friction-reduction, greater surface-area, and anti-wear-ability support enhancement in properties. In addition, Zhang et al. also observed oleic acid-modified graphitic nature lubricant [40]. Tribological properties were investigated by employing four-ball tribometer relevant to oily surface-modified graphene. **Figure 6a, b** illustrates lubricant optimized-graphene with contents (0.02–0.06 wt.%), exhibiting improved-friction as well as anti-wear activity, 17% friction-coefficient whereas 14% wear scar-diameter respectively. Desired friction behavior has been elaborated by

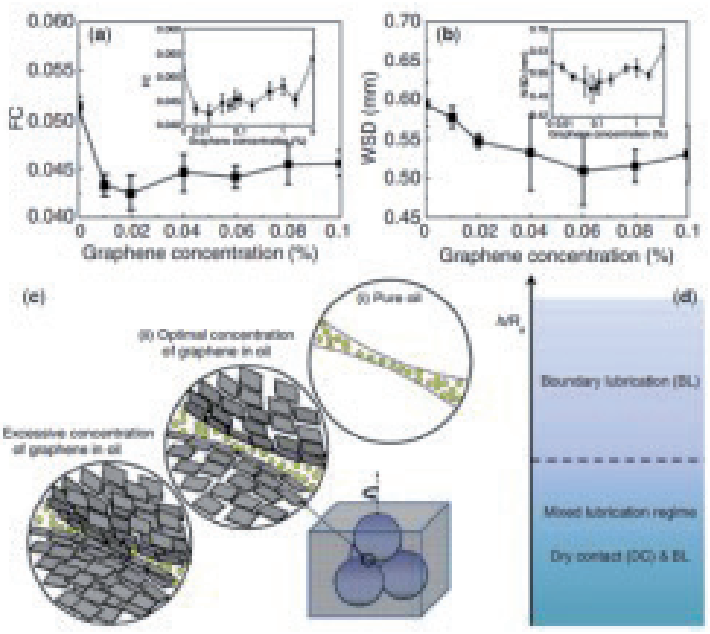

Figure 6.
Four-ball test results: ***(a)*** *FC versus graphene concentration;* ***(b)*** *WSD versus graphene concentration;* ***(c)*** *schematic diagram of the tribological mechanism of graphene sheets as oil additives;* ***(d)*** *lubrication regime transition [40].*

proposed tribological activity as shown in **Figure 6c**. Graphitic protective-layer became prominent on each steel ball surface separately with less concentration, thereby introducing improved anti-wear performance. On the other hand, oily films become discontinuous with higher density that is considered responsible for antiwear-degradation properties. Lin et al. investigated (0.075 wt%) stearic with oleic-acid modified graphitic nature in oil tunes wear-resistance along with load-carrying machine efficiency [41]. Current reports also presented that alkylated graphitic organic solvents may show lubricant behavior to improve properties [42]. Alkylated-graphene with different alkyl-chain-length (Cn = 8, 12, 18) is synthesized by condensed medium reaction (alkylamine+$SOCl_2$-activated GO). It was investigated through octadecyl amino-graphene mixed with hexadecane. In this case, reduced friction along with wear concentration (26% and 9%) was obtained compared with hexadecane.

2.4 Nanofluids

Loss of energy in the form of heat energy slows down performance of various instruments and mechanical technology. Instrument and machinery performance may be improved by using some fluids such as DI water, transformer oil, and heat-sensitive fluids. Heat transfer capability of fluids is less enough caused by the deterioration of productivity and lifetime of equipment and machines and also electronic circuits. To prolong heat transfer efficiency, the addition of nanomaterials addition is increased in fluids that may further improve the efficiency. Baby et al. reported thermal conductivity that may be increased upto14% with temperature (25°C) and deionized water is used as base-fluid showing fraction by volume of only 0.056% [43, 44]. Moreover, thermal conductivity is increased upto 64% at 50°C but with same contents belonging to modified-graphene. Ghozatloo et al. observed 0.06 wt% functionalized-graphene may improve thermal-conductivity (14.2%) when treated in water (25°C) [45]. Finally, thermal-conductivity is enhanced (18%) when the temperature is increased to 52°C.

2.5 Graphene-based transparent and flexible conductive films for displays and electrodes

Graphene is incorporated into electronics field by employing transfer printing along with solution-based approaches. Chhowalla et al. [46] suggested an efficient approach for smooth deposition with effective control of reduced graphene oxide in the form of thin films having thickness like single-monolayer to several-layers ranging large areas. Optoelectronic properties are tuned over reasonable order of magnitude that presents potentially beneficial towards transparent semiconductors as well as semi-metals. The thinnest films show graphitic ambipolar-transistor behavior. However, thick films behave like graphitic semi-metals respectively [47, 48]. Consequently, suggested deposition in this approach offered new routes to translate fundamental properties relevant to graphene into viable devices. Furthermore, large-scale transparent electrode growth has been successfully presented by Hong et al. [49] In this work, chemical vapor deposition technique was employed on thin nickel films. Two methods were applied for the formation of films and thereby transferring also to arbitrary substrates. Graphene films exhibited sheet resistance as well as optical transparency at desired level respectively. Graphene monolayers were transferred to SiO_2 substrates showing electron mobility at faster rate along with half-integer (quantum Hall effect). High-quality graphene was grown by CVD that presented better results as compared with mechanically cleaved graphene as illustrated in **Figure 7a**-**c**. Owing to extraordinary mechanical properties, graphene demonstrated macroscopic use upto maximum level, resulting in conducting electrodes and transparent electrodes in (flexible and foldable) electronics [50].

In addition, superior optical and electronic graphene properties i.e., high mobility, optical behavior, flexibility trend, and environmental stability are accounted for promising material attributing to applications towards photonic as well as optoelectronic fields. In this support, comprehensive literary work has been done favorable for graphene photonics, optoelectronics, and other applications were offered by Ferrari et al. [51]. From scientific contents included in the review clearly show graphene-based conducting films and graphene oxide (GO) based conducting films that were used in synthesis of various photonic with optoelectronic devices. Equipment such as inorganic and organic electrodes of dye-sensitized solar cells, light-emitting diodes as well as electrochemical cells, touch screens, graphene-based absorbers.

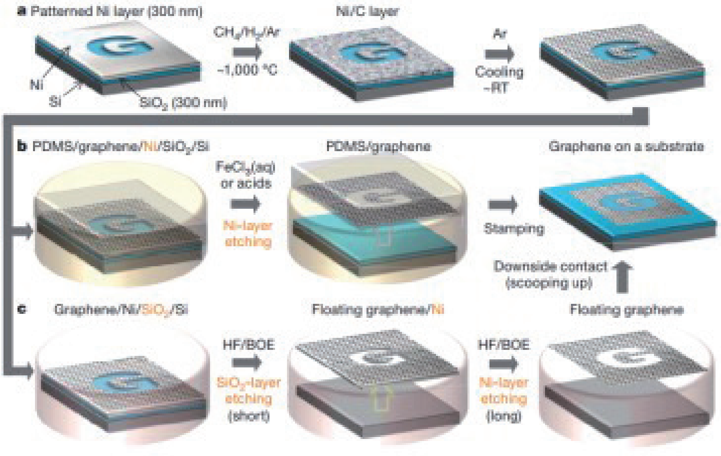

Figure 7.
Synthesis, etching, and transfer processes for the large scale and patterned graphene films, ***(a)*** *synthesis of patterned graphene films on thin nickel layers* ***(b)*** *etching using $FeCl_3$ (or acids) and transfer of graphene films using a PDMS stamp* ***(c)*** *etching using BOE or hydrogen fluoride (HF) solution and transfer of graphene films.*

Graphene electrodes showing high-performance field-effect transistors have been fabricated by Kim et al. [52]. To optimize performance of devices, authors controlled work-function attached with graphene electrodes via functionalization of SiO_2 substrate surface. NH_2 may donate electrons that are considered terminated SAMs but they are induced n-doping strongly in graphene. On the other hand, CH_3-terminated SAMs contributed neutralized p-doping that was strictly induced through SiO_2-substrates. Resultantly, graphene electrode work function considerably changed. Moreover, SAMs were observed as pattern-able robust yield. Besides, output of work may also be used towards fabrication of various graphitic nature compounds that paved foundation of electronic as well as optoelectronic devices.

Graphene films indicate mechanical along with optical properties as compared with other transparent-thin-films, particularly in photonics and optoelectronics. However, as far as conductivity is concerned it is inferior as compared with conventional (ITO) electrodes having comparable transparency and resulting in lower performance of devices working on graphene-based transparent thin films. Ahn et al. [53] presented an effective method to overcome deficiency and to improve graphene films concerning performance towards electrostatically doping that was employed through ferroelectric polymer. Aforesaid graphene films showing ferroelectric polarization have been used for the preparation of ultrathin organic-solar-cells (OSCs). Graphene-based OSCs have explored superior efficiency as well as superior stability as compared with graphene-based OSCs that were chemically doped. Moreover, OSCs fabricated by ultrathin-ferroelectric-film act as substrate with few micrometer sizes, exhibited attractive mechanical flexibility as well as durability. In the last, these may also be rolled up into cylindrical shapes having 7.5 mm diameter size.

2.6 Graphene-based separation membranes

Graphene nanopores sheets are used as separation membranes emerging and covering various since theoretical studies that were presented by Král et al. [54]. They were labeled modified nanopores incorporated graphitic type monolayers thereby resulted from molecular dynamic-simulation providing superior realm of hydrated ions. The ions in a partly stripped state connected with hydration shells may penetrate through infinitesimal pores having diameter ~5 Å, such as fluorine with nitrogen terminated-pores permit flow of Li^+, Na^+ and K^+ like positive ions having ratio 9:14:33 systematically whereas negative ions are strictly prohibited. On the other hand, hydrogen-terminated pores accelerate F^-, $Cl^-$and Br^- anions along with a specific ratio 0:17:33 rather it blocks cationic passage. Aforesaid nanopores may provide versatile promising applications, particularly towards molecular separation and energy storage devices respectively.

In addition, Jiang et al. [55] contributed the work that dealt with permeability as well as selectivity related to graphene sheets structured with nanometer-scale pores adopting density functional theory for necessary calculations. Researchers investigated superior selectivity order of magnitude that was 10^5 for H_2/CH_4 showing excellent performance from H_2 side in the situation of nitrogen-treated pore. Furthermore, report writers investigated selectivity at an extremely higher order of magnitude equivalent to 10^{23} for H_2/CH_4 for all hydrogen functionalized pores with width infinitesimally 2.5 Å, presenting a barrier (1.6 eV) for methane (CH_4) whereas surmountable for H_2 with magnitude 0.22 eV. These results exhibited that pores are considered superior to polymers as well as silica membranes. Whereas bulk solubility along with diffusivity is plays a dominant role to transport gas molecules throughout the material. Outcomes suggested one atom thin porous-graphene-sheets behave such as highly efficient and selective membranes relevant to gas separation. Aforesaid types of pores may occupy a widespread impact concerning various energy devices with technological applications.

The molecular-dynamic-simulation employed by Xue et al. [56] explored CO_2 separation strategy from that of CO_2 mixture whereas N_2 gas through porous graphene-membranes. Graphene sheets are chemically functionalized to observe its effects while porous graphene membranes performance for separation has been controllably examined. Researchers investigated chemical functionalization of graphene sheets that may increase absorptive capability of CO_2 gas. On the other hand pore-rim chemical-functionalization significantly enhanced CO_2 selectivity over N_2 gas molecules. The results demonstrated versatile use of functionalized-porous-graphene for CO_2 as well as N_2 separation. Resultantly authors suggested an effective strategy, improving gas separation activity of porous-graphene-membranes [57].

Nanoporous graphene use for water desalination has been suggested by Grossman et al. [58]. Through employing classical-molecular-dynamics, this work presented nanometer-scale porous single-layer-graphene that may prove filter of (NaCl) effectively from that of water. Furthermore, authors researched desalination-performance corresponding to membrane exploring functioning of pore-size, chemical-functionalization as well as applied-pressure. The results indicate membrane's ability that prevents salt penetration and all depends on the porous-diameter size along with sized pores suitable for water flow whereas passage of ions was banned. Further investigation indicates role of functional-groups appeared at graphene-edges in hydroxyl group may form commonly double hydrophilic nature. However, water flux is increased taking place by the reason of salt rejection activity with less amount corresponding to capability of hydroxyl group substituting water molecules in hydration-shell of ions. Collective and achieved outcomes that explored water-permeability of relevant material were clearly in higher magnitude as compared with reverse-osmosis membranes conventionally, thereby NPG may perform valuable role play towards water refinement [59, 60].

The same period was covered by Karnik et al. [61] study also who selectively suggested transport of molecules employing intrinsic-defects single-layer (CVD) graphene. In this case, small measured area was identified greater than 25 mm^2, but in turn it was transferred on porous polycarbonate-substrate. The collective contribution of pressure-driven as well as diffusive- transport with precise-measurement presented confirm evidence with respect to size-selective- transport of material molecules passing through membranes. They were attributed to low-frequency presence within 14 nm range diameter size pores relevant to (CVD) graphene as describe in **Figure 8**. Consequently, authors have proposed first step towards the occurrence of graphene-based selective- membranes [62–65].

Previous work was progressively continued [66] for molecular-sieving by employing porous- graphene. In this respect, Bunch et al. [67] also fabricated valves to control gas-phase-transport through graphene containing discrete nano-sized pores. Reports have revealed and identified gas-flux passing through discrete nano-size pores present in monolayer-graphene that may be detected as well as controlled employing nanometer-size gold clusters. These clusters are centered on graphene surface by migrating pores but partially block them also. However, samples containing not gold-clusters indicate stochastic-switching of magnitude of gas molecules attributing rearrangement of desired pores. Additionally, previously fabricated molecular valves may be involved particularly to progress ideal approaches towards a molecular synthesis that are considered foundation for controllable switching concerned with molecular gas flux [68, 69].

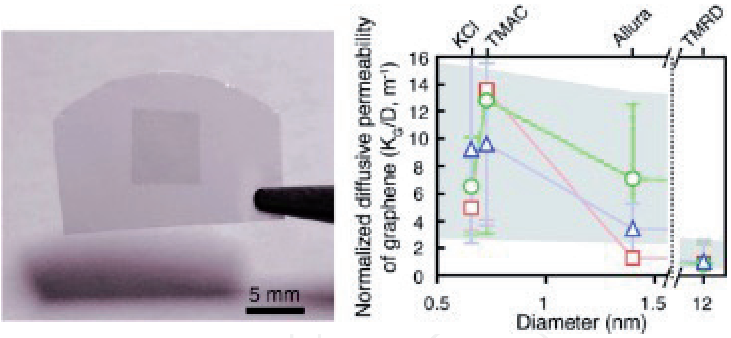

Figure 8.
(a) Graphene composite membrane (GCM) consists of large-area graphene on polycarbonate track etch (PCTE) membrane, (b) permeability of the CVD graphene, KG, calculated for the three membranes using a simple circuit model (inset), indicated as a function of the diameters of the molecules. Only two pores, one of which is covered by graphene, are shown for clarity. The gray region denotes the continuum model prediction for graphene of porosity between 0.025% and 0.15% [61].

2.7 Biosensors

Sensors are regarded as those devices that may identify changes in occurring events. Various studies have reported CNTs to use concerning sensors such as chemical, thermal, biological, and gas respectively. In addition, CNTs may also behave like flow sensors [70, 71]. It has been observed that liquid flow on SWCNTs bundles creates voltage normally in flow direction, and may be used in near future in the form of micro-machines working in a fluid medium, for example, heart pacemakers working without heavy-battery as well as recharging [70]. Piezoresistive sensors based on pressure may be prepared using CNTs. SWCNTs have also grown on polysilicon membranes [72]. Uniform pressure creates change into resistance of SWCNTs that was observed in membranes. From viewpoint of Caldwell et al. [73] piezoresistive fabrication offered pressure sensors for CNTs that may bring changes dramatically to biomedical industry and various piezoresistance diagnostic nature as well as therapeutic devices have recently applied in sensor field. Moreover, CNTs fabricated biosensors are used to detect deoxyribonucleic acid concentration in the body. Aforesaid instruments also detected specific parts of DNA corresponding to particular type of disease [74]. Sensors previously mentioned become capable to detect only few molecules of DNA containing specific sequences, thereby increasing probability to diagnose patients possessing specific sequences that are closely related to cancerous genes. Furthermore biosensors have been suitably used for the sensing of glucose. CNTs chemical-sensors, especially for liquids, may also use sensing capability to investigate blood completely or partially. In this case, biosensors are proposed favorable to detect sodium as well as to find pH value accordingly [75].

Having small size with owing attractive electrochemical properties, carbon nanotubes contribute a great part as a component of biosensors. Additionally, CNTs fabricated electrodes possess interesting electrochemical properties as compared with previously available electrodes and show superior quality [76]. CNT-based biosensors present a high aspect-ratio that enables tubes to become embodied into proteins so that electron transferring included with enzymes frequently occur such as glucose oxidase where redox centers are observed not normal to be accessible (See **Figure 9**) [78]. Moreover, chemically modified CNTs have become an effective approach to contribute selectivity property into resulting biosensors that have sufficiently exploited towards exploring sensitivity to detect DNA molecules [79]. However, in near future, fine efforts may be expected to direct towards preventing biomolecules that may be absorbed on surface of tube walls, whereas promising advances have previously contributed a great part in this respect [80]. Further

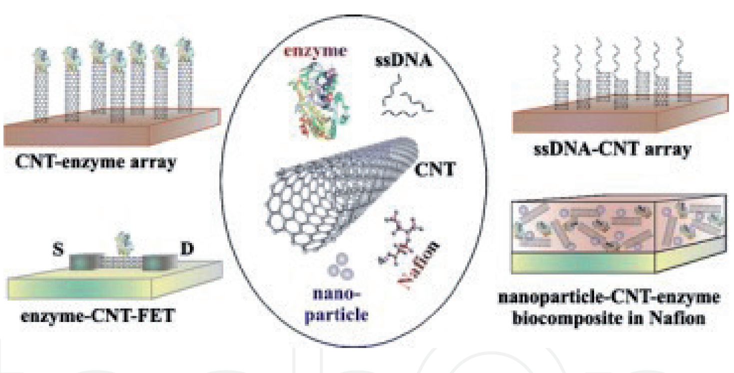

Figure 9.
Schematics of synthesis process DNA based biosensors [77].

advancements may extend range of molecules to be modified that are considered attachable to nanotubes whereas enzymes, as well as nucleic acids along with some metal nanocrystals, are numerously employed to meet the need so far. Particularly respect is electropolymerized coatings have been appreciated that may be prepared with various concentrations, having precise and controllable thicknesses [81].

2.8 Fuel cells

As far as fuel cells are concerned, they are utilized for conversion of chemical energy into electricity directly with great efficiency and exhibited excellent results towards different applications [82–84]. In the fuel cells, catalysts on membrane surface are especially PEM made from graphene. Recently numerous investigations are under progress assessing probability for substitution of platinum catalyst with metals or metal oxides and with nitrogen functionalized metal catalyst [85, 86]. However, some catalysts face issues such as stability as well as activity as compared with platinum catalyst. Active carbon exhibits capability for meeting said challenges yet they tend to occupy certain limitations accordingly. They possess high surface area owing to have instability thereby raising major issues unless coupled with suitable material for this purpose. Graphene technological development made by active carbons has suggested stronger substitutes to platinum occupying high conductivity whereas surface area is considered high along with adhesion property for the catalyst [87, 88]. Graphene oxide, a derivative of graphene resides large number of functional groups making them best for nucleation sites such as catalyst nanoparticles randomly locate on and edges of the surface [89]. The extensive use of graphene is indicated in fuel cells showing supporting material to anode catalyst and replace also cathode catalyst as well as standalone electrolyte membrane and bipolar plates. All work may be summarized concerning role of graphene in various component forms. Platinum, as well as alloys, are supposed as conventional catalysts in the electrodes of fuel cells. They are either an anode or cathode located in fuel cells. These fuel cells are fed by hydrogen and other hydrocarbon methanol [90] as well as ethanol [91]. Platinum is expensive as well as limited in availability and also caused by the produced intermediates while oxidation reactions are carried out at different fuels [92]. Various approaches were employed to reduce catalyst loading or complete replacement of Pt catalyst by using non-precious catalyst reactions at anodes [93] as well as cathode [94] terminals of fuel cells.

2.9 Supercapacitors

Supercapacitors harvest excellent properties such as energy density, ultra thinness, and long life, and therefore have proven promising candidates in electrochemical energy-storage systems [95–97]. Initially, supercapacitors may be categorized into electrical double-layer as well as Pseudo-capacitors depending on energy-storage mechanisms. In first category, charges accumulate electrostatically at electrode and electrolyte interface through formation of an electrical double-charges layer. Charge-storage is uniquely physical essence showing no chemical reaction yet is called non-faradaic process. Electric-double-layer behaves like dielectric whereas capacitance proves direct-function owing to surface-area of electrode. Therefore, carbon-based nanomaterials possessing great surface-area for electrodes increase capacitance of electrical double-layer capacitors. Charge –discharge functioning is indicated by ion absorption-desorption capability of EDLC. Ions are directed forming EDL at the time of voltage application at electrodes which in turn charge EDLC for controlling purpose. It has been observed that carbonaceous electrodes exhibit fine electrochemical surface-area inheriting large porosity caused by creating enhanced interfacial-area forming prominent EDL. Carbonaceous materials have attractive electrical properties owing to which are labeled as basic type of EDLC [98]. Unlike EDLC nature, Pseudo capacitors show capability of fast (Faradaic) charging with transfer-reactions that are carried out at solid electrodes as well as electrolytes. As a result, faradaic-charge-transfer is an applied voltage-dependent system. Fundamental electrochemical reactions in pseudocapacitance involve chemisorption along with electro-sorption from electrolyte. Redox (oxidation and reduction) reactions attractions from electrolyte thereby producing intercalation/de-intercalation sites relevant to active electrodes. Previous electrochemical processes are proposed as surface dependent. In order to promote electrochemical properties attributing to capacitors, great efforts were devoted to making functionalization/hybridization related to a variety of materials or nano-structured optimized promising candidates [99].

3. Conclusions and future directions

Advanced carbons materials such as graphene and CNTs are considered key merits for affordable energy conversions and storage versatile applications. The investigation explored the latest technological advancement during synthesis of the said advanced materials whereas characterizations are performed with respect to current day applications. CVD technique often leads to production of nanostructures having porous networks showing good conductivity. Since quality improvement is the main goal of research work of relevant material, so is improved significantly through employing such technique. Growing concerns are also expected concerning scalability adopting this approach reasonably. Furthermore, characteristics and performance are achievable towards graphene as well as graphene oxide equally growing concern size with quality of graphene-oxide-precursor. The investigation related to novel techniques are aimed to enhance into inter-sheet- binding is considered another novel direction towards research purpose. Desired characteristics are proposed to be achieved through merging graphene sponges as well as polymers. As far as research-based graphene applications are concerned, they belong to several energy storage/conversion devices that are considered still novel in research activities. Graphene suitability has exhibited electrochemical properties prominently and for electrochemical purposes accordingly.

Peculiarities related to graphene as well as graphene oxide compared to allotropes of carbon were also discussed in detail. Aforesaid merits include such as excellent surface-area, high conductivity, great solubility, facile synthesis, and cheap source material as well. Though various technological advancements were explored yet space is available for improvement particularly for both electro-analytical and electrochemical sensors. Some of other electrochemical applications related to graphene oxide are still extendable covering further electrochemical applications towards future directions. Furthermore, critical challenges are still associated with such material as facile synthesis has been critically addressed. The structure of graphene oxide is also still incomplete at molecular level and therefore considered more important in literature. Other focus areas are supposed to be an understudy for further attention with respect to defects concerned with conductivity of graphene oxide. A brief understanding of electron flow on graphene oxide substrate/interface will also be an empty area of research available for further enhancement towards graphene oxide as well as other applications. Designs and approaches adopted, up till now, associated with manufacturing of graphene oxide devices are suggested critical in the future status of this material. Despite the aforementioned and highlighted challenges, graphene oxide applications associated with electrochemical sensors remain the key future application of graphene oxide.

Author details

Muhammad Ikram[1], Ali Raza[2], Khurram Shahzad[3], Ali Haider[4], Junaid Haider[5], Abdullah Khan Durrani[3], Asim Hassan Rizvi[3], Asghari Maqsood[6] and Mujtaba Ikram[3]*

1 Solar Cell Applications Research Lab, Department of Physics, Government College University Lahore, Punjab, Pakistan

2 Department of Physics, Riphah Institute of Computing and Applied Sciences (RICAS), Riphah International University, Lahore, Pakistan

3 Institute of Chemical Engineering and Technology (ICET), University of the Punjab (PU), Lahore, Punjab, Pakistan

4 Department of Clinical Medicine and Surgery, University of Veterinary and Animal Sciences, Lahore, Punjab, Pakistan

5 Tianjin Institute of Industrial Biotechnology, Chinese Academy of Sciences, Tianjin, China

6 Nanoscale Laboratory, Department of Physics, Air University, Islamabad, Pakistan

*Address all correspondence to: mujtaba.icet@pu.edu.pk

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