



Preparation and Characterization of Multilayer Graphene via Electrochemical Exfoliation in NaCl Solution

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Abstract

Graphene is two Dimension-carbon based nanomaterial, and unique properties of the graphene made it interest to researchers. The objective of this work was to address the need for low-cost, efficient graphene preparation; the electrochemical exfoliation process and photosynthesis of the exfoliated solution were used. In this study, the exfoliated graphite mixture. The exfoliated graphite (Gr2, Gr3, Gr4) (0.08, 0.1, 0.2 M NaCl, respectively) was dried by sunlight and investigated; the results confirmed of multilayer graphene by Raman, UV-Vis, FESEM/EDS, grain size 4–9 μm). Behavior of UV analysis related with number of single and multilayer of graphene depends on conjugative effect that arises from nanometer-scale sp^2 clusters, and chromophore units as well as functional groups, also oxygen clusters may be removed and disappear the shoulder. FTIR peaks confirmed peeling off graphene layers. One of the most important reactions is the incorporation of Cl atoms into unsaturated sites. Grain size increased with increasing voltage, while it decreased in (0.2 M) NaCl. FESEM showed a smooth, crimped surface. EDS analysis appeared C/O ratio of (7.6, 4.6, 1.26), with Cl and Na observed in rinsed Gr3. D, G, and 2D peaks were displayed by Raman spectroscopy. In this study, it was concluded that NaCl-assisted exfoliation is a simple and low-cost route.

Keywords: Graphene, Electrochemical Exfoliation, NaCl, UV, Fourier Transform Infrared (FTIR), Raman, Particle Size Analysis

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1. Introduction

Carbon nanomaterials included many kinds, one of them is Graphene family nanomaterials (GFNs), with nanometers thickness and lateral dimensions in micron [1]. Graphene crystal structure consist of layer of 2D, sp^2 -hybridized carbon [2]. First discovered of Graphene by Geim and Novoselov in 2004, recently become a very common material with a wide range of applications [3]. Graphene received significant attention, it has excellent properties like high thermal conductivity, high electron mobility, stiffness and extraordinary elasticity [4], high tensile strength 200 times stronger than steel [5]. Graphene investment have been done in several applications, this is required to synthesis graphene in large quantities and high quality, and in turn require facile, scalable, and low cost synthetic method [6]. Currently, different methods for produce graphene have been used, mainly including chemical and mechanical exfoliation of graphite, chemical vapor deposition (CVD) [6]. Recently, electrochemical exfoliation process emerged as a very promising approach in exfoliation of graphite, and solve one of the most pressing issues that impede the widespread application of graphene in real-life [7].

Recently, numerous researches appeared in synthesis of graphene; it is possible to start with a study of Munuera *et al.* reported the anodic exfoliation of graphite in the water using NaCl as co-electrolyte, and introduced a particularly straightforward, cheap, and available material as an alternative oxidation preventing (co-electrolyte), lowest oxidation (O/C) ratio (~ 0.02 - 0.03) [7]. Kamali *et al.*

examined economic process, electrochemical exfoliation of G in molten of sodium chloride under Archon-4%hydrogen gas atmosphere, role of hydrogen in the exfoliation method is highlighted, exfoliated rate was demonstrated to be (200 g/liter) of molten NaCl / day [8]. Alinejad *et al.* found that adding NaCl into graphite during milling allows in obtaining nano-flakes of graphene. Brittle and harder NaCl particles serving as milling agents by both helping to chop and preventing agglomeration. Probable mechanism of synthesis may be explained by graphene and NaCl sliding or slipping against and over each other [9]. Niu *et al.* used a facile and low-cost technique to exfoliate graphite powders directly into large-size, solution-dispersible, and high-quality few-layer graphene sheets, aqueous mixtures of graphite material and inorganic salts materials (NaCl and CuCl_2) are stirred, and dried by evaporation subsequently, the graphene contain little of O, and (86%) of them are (1–5) layers [2]. Shi *et al.* used CVD to creation few layers of graphene on micro crystalline NaCl powder, via a facile and low-cost method in water-soluble NaCl, planes of micron NaCl crystal play role in nucleation and growth of few layers graphene [6]. Munuera *et al.* have been prepared graphene material by anodic electrochemical delamination of graphite in NaCl as electrolyte. Contrary to previous conflicting reports on halide anions ability to act as efficient electrolytes, this research show that the suitable choice of both electrode and concentration of sodium halide leads to generation single-/few-layer graphene in large quantities and oxidation degree (O/C ratio ~ 0.06) lower than that of graphenes anodically exfoliated in other electrolytes used commonly. It is thought that the halide anions are

play a role in mitigating graphene oxidation during exfoliation process [10]. Abid Ali et al studied graphene synthesized by using different electrolytes (H_2SO_4 , NaOH , Na_2SO_4 , KOH and ($\text{NaOH} + \text{H}_2\text{SO}_4$)) with different PH(0.5,1.5,2) and voltages (5v,8v,11.5v), optimum conditions were established to be an applied voltage of 11.5V, and a pH of 0.5 in acidic electrolyte [11]. Aims of this study was to preparation and investigate the graphene synthesized by electrochemical exfoliation process in electrolyte (NaCl + distilled water) and utilized photochemical transformation in drying process of exfoliation liquid.

2. Experimental Procedure

2.1 Material

Graphite rods, NaCl have been used in this study, different concentrations (Table 1) of NaCl dissolved in distillate water used as electrolyte.

Table 1. NaCl concentration as electrolyte

Sample	NaCl concentration	Distillate water
Gr2	0.08M	400ml
Gr3	0.1M	400ml
Gr4	0.2M	400ml

The advantage of NaCl over acidic or alkaline electrolytes in terms of yield, quality, or environmental impact can be listed in number of points, salt (NaCl)-assisted exfoliation is a simple, low-cost, high exfoliation efficiency, separate graphene sheets mechanically rather than chemically oxidize them, NaCl is inexpensive, non-toxic, and easy to remove by washing or evaporation, making the process cheaper and greener than using expensive surfactants, or chemical oxidants. The approach gives larger batch or continuous processing compared with multistep chemical syntheses. Salts can assist dispersion without strongly adsorbing to the graphene surface and not require extra cleaning or degrade device performance.

2.2 Characterization Techniques

Characterization specific measurements can be obtained from interaction of light with graphene that affected by oxidation level, agglomeration state, and grain size. Power supply (YAXUN PS-305D, Variable 30V 5A DC) utilized in electrochemical exfoliation process of graphite. Tests have been involved UV-Vis spectroscopy recorded on (1900 - Shimadzu), FTIR demonstrated by (1800-Shimadzu), laser particle size analyzer (Better size 2000), and Raman spectroscopy performed by (N1541-Tescan). Morphology characterized in (Mira3 Tescan) to obtain scanning electron microscopy (SEM) images.

2.3 Preparation of graphene

Electrochemical exfoliation process utilized in preparation of graphene materials, shown in fig.1.

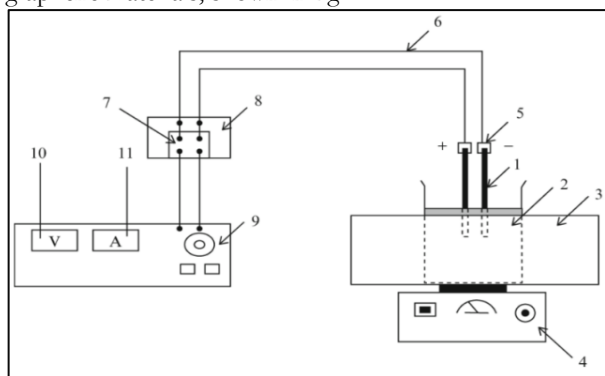


Figure 1. Schematic design of the electrochemical system, 1. Graphite; 2 the electrolyte. 3. Water bath for cooling. 4. Stirrer. 5. Contacts. 6. Connectors. 7. timer. 8. Switch. 9. AC rectifier. 10. the volt-meter. 11. Aperture.

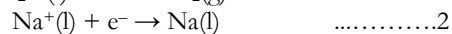
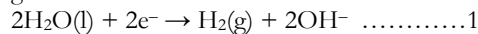
Schematic diagram shows in Fig.1 is experimental setup used for electrochemical exfoliation process. Two graphite electrodes immersed in different concentration (0.08M, 0.1M, 0.2M) of electrolyte (NaCl) and 400ml distillate water, different voltages applied (11v, 12v, 13v). Once supplied of DC voltage, ions start to intercalation through interlayers of graphite.

Peeling occurs at electrode surface gradually and exfoliated into graphene pieces in exfoliation liquid as shown in Figure 2. Large graphite flakes that settled to the bottom have been separated from exfoliation liquid and put the last in a petri dish to dried by exposing to sunlight for ≈ 10 hours. Some of powders rinsing and washing by distillation water before ultrasonic treatment, thereafter characterized.

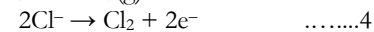
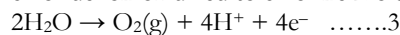
2.4 Mechanism of exfoliation process

Aqueous electrolyte is important for creating of ions that initiate exfoliation of graphite electrodes, NaCl have been used as electrolyte in exfoliation process. Lee et al. indicated that there are subtle conditions enable the intercalation of Cl^- into the graphite [12]. Electrolysis of aqueous sodium chloride divided into:

At Cathode, reduction reaction: water may be reduced to hydrogen gas or Sodium ions reduced to sodium metallic.



At anode, Oxidation reaction: Water may be oxidized to oxygen or chloride ion oxidized to chlorine molecule.



Hence, the expected products (Na , H_2 gas) liberated at cathode, O_2 and Cl_2 gases are liberated at anode. Presence of negative intercalation ions Cl^- , OH^- and gas molecules, as well as applied voltage causing peeling off of the electrode as shown in fig.2. Once flow of current of electricity in the cell, ions initiate to anodic delamination of graphite electrodes, intercalated between layers and expand space of the interlayer in graphite and facilitate the process of exfoliation. Contrary to the conflicting previous reports about the halide anions ability to act as efficiency electrolytes in graphene exfoliation, Munuera et al. showed that suitable choice of both graphite electrode and NaCl concentration assist in generate large amount of G nano-sheets and lower oxidation, it is thought a role of halide anions in mitigating effect of oxidation on graphene lattice [10].

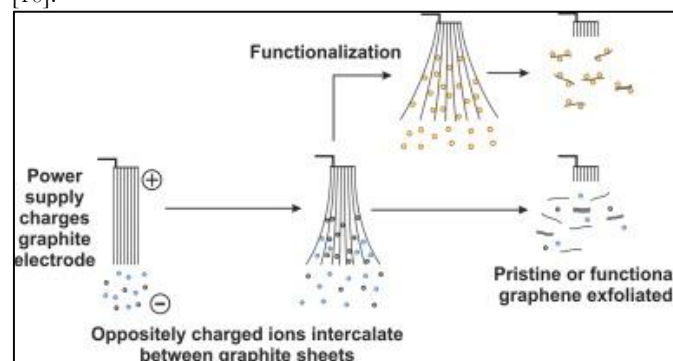


Figure 2. schematic the role of Cl^- and OH^- ions in electrochemical exfoliation process.

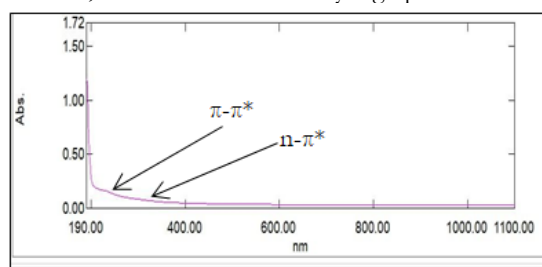
3. Results and discussion

Samples have been termed (Gr2, Gr3, Gr4) according to NaCl concentrations (0.08M, 0.1M, 0.2M). Previous studies utilized sunlight in some physicochemical changes of nano-materials when existent in aqueous media, irradiation caused by from sun degrade and reduce of material to rGO [13]. Irradiation leads to oxidative formation (valence band holes(hvb)) and reductive formation (conduction band electron, (eq^-)) transients, hvb may affect

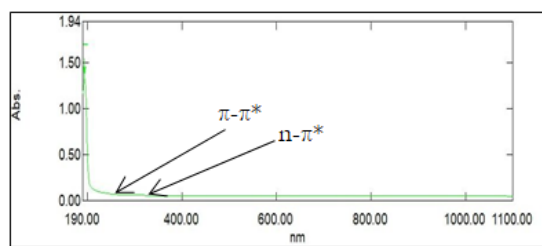
oxidation of O-functional groups easily, while eaq^- promotes C-Cl generation [13], single atoms of chlorine bonded to each atom of carbon from various sides of graphene with (sp^3 -type) covalent bonds [14]. NaCl as additive effective in preventing oxidation, it is popular and low priced material, attractive in scaled up the graphene production. Reduction potential (standard) for pair (Cl^-/Cl_2 pair, +1.37V) is lower than that of ($\text{OH}^\bullet/\text{OH}^-$ pair, +1.9 V). Oxidation at edges is requirement to proceed anodic exfoliation that increasing interlayer spacing locally at the edge and penetration of other anions that acting as a sort of wedge [7]. Liu et al. reported that the halide anions acted as sacrificial agents to react with ($\text{HO}^\bullet$) radicals and limited its attack on graphite lattice [15].

3.1 UV analysis

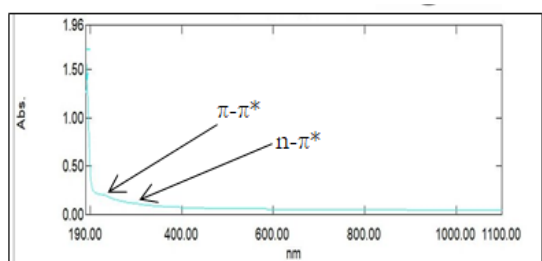
UV analyses have been demonstrated for Gr2, Gr3, Gr4, the behavior of UV analysis related with number of single and multilayer of graphene depends on conjugative effect that arises from nanometer-scale sp^2 clusters, and chromophore units. As shown in Fig.3, exhibits weak intensity peak observed at ≈ 230 nm that corresponds to ($\pi-\pi^*$) plasmon peak, as well as weak peak for ($n-\pi^*$). Shoulder intensity decreases and disappears with increasing number of multilayer Graphene (thick layer Graphene). This behavior allowed qualitative analysis of Graphene dispersions [16]. Absorption peaks are affected by the functional groups due to conjugate systems, and change the absorption peaks, oxygen clusters may be removed and disappear the shoulder [17] [18]. shoulder disappears may be due to fewer oxygen groups, larger conjugated domains, more restacked multilayer graphene.



-a-



-b-



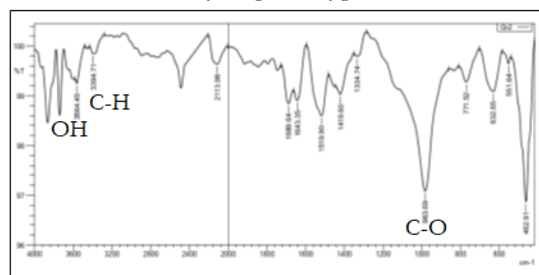
-c-

Figure 3. UV analysis of : a-Gr2, b-Gr3, c-Gr4

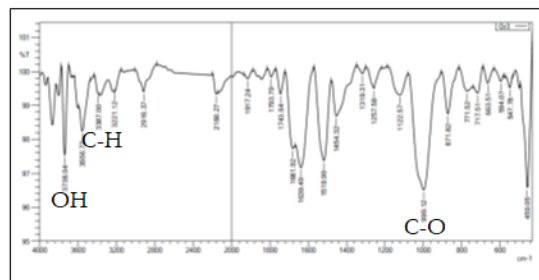
3.2 FTIR analysis

Surface chemistry of graphene and responsible of ions for peeling off graphene layers are confirmed by recorded of FTIR spectra.

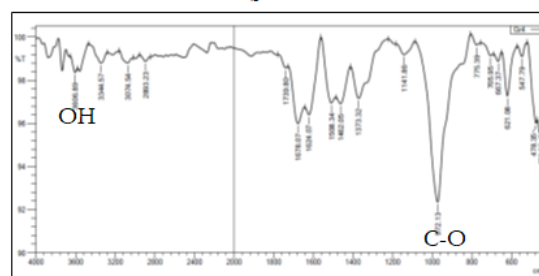
These peaks are mostly assigned to functional groups created between elements hydrogen, oxygen and carbon as well as Chlorine.



-a-



-b-



-c-

Figure 4. FTIR analysis of: a-Gr2, b-Gr3, c-Gr4

Figure 4 refer to characteristic peaks observed for samples Gr2 Gr3 Gr4, located at 547, 594.07, 663.51, 717.51, 771.52, 871.82, 1122.57, 1257.58, 1319.31, 1639.49, 1681.92, 1743, and 3387 cm^{-1} .

One of the most important reactions is the incorporation Cl atoms into unsaturated sites [13]. C-Cl vibration band localized between 550-850 cm^{-1} as can be seen in the results adopted from [19][20]. C-O-C band (at 1122.57 cm^{-1}) C=C {at 1639.49 cm^{-1} (stretching)} [21], C-O (at 1257.58 cm^{-1}), (C=O, C=C) (at 1681.92) [5][22], C-O-C (at 1319.31), C=O stretching (at 1743 cm^{-1}) [5], other study referred that the bands in the range (3000-3500) is concerning with the hydroxyl group [23]. Small absorption of (O-H) stretching vibrations at 3387.00 may be reduced due to deoxygenating [24]. Peaks assigned to oxygen-containing groups—including C-O-C, C-O, C=O, and O-H reflecting partial oxidation of graphite structure during intercalation and exfoliation. The weak intensities of oxygen-related bands suggest that only a limited amount of O-functionalities remained after sunlight-induced photochemical reduction. Overall, the FTIR results confirm successful exfoliation accompanied by mild functionalization and the presence of residual Cl- and O-containing groups, consistent with the expected mechanism of electrochemical exfoliation in NaCl media.

3.3 Particle Size Analysis

The electrolyte plays important role on the yield and quality of the graphene produced. The yielding required can be produced from the successful combination of the electrolyte concentration and applied voltage. Niu et al. have been showed increases of exfoliation efficiency in presence of inorganic salts, and efficient synthesize to produced large-sized graphene sheets [2].

Figure 5 refer to the relation between grain size of graphene and voltage, observed grain size increased with increasing voltage in (0.08M) NaCl, while decreased in (0.2M) NaCl. In this study, graphene was synthesized with average grain size (4-9) μm , may be related to effect of concentration, as well as restacking process of graphene after some time.

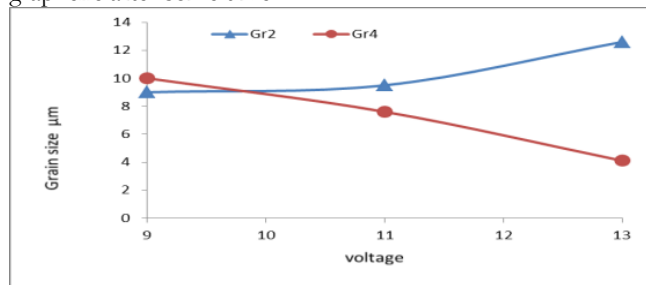


Figure 5. grain size – voltage relation

3.4 FSEM and EDS

FSEM is used to examine the surface topography of the starting graphite material and exfoliated graphene with energy-dispersive X-ray (EDX) analysis determining the C/O ratio.

Figures (6 and 7) refer to FESEM images of the graphite and as-prepared graphene obtained with NaCl as electrolyte. Figure 6 showing natural graphite consist of thick layers of graphitic stacks composed of layered but compactly fastened Nano-sheets. Figure 7 illustrate the surface of the sheets (Gr2 sample) after exfoliation in NaCl electrolyte and appears to be smooth and crimped at the edges.

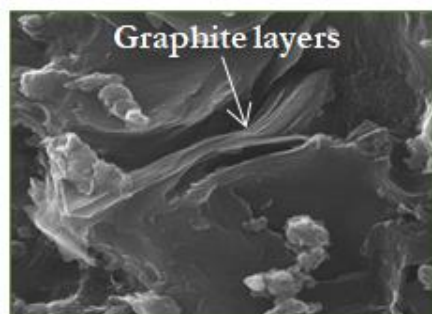


Figure 6. show SEM for start material (Graphite)

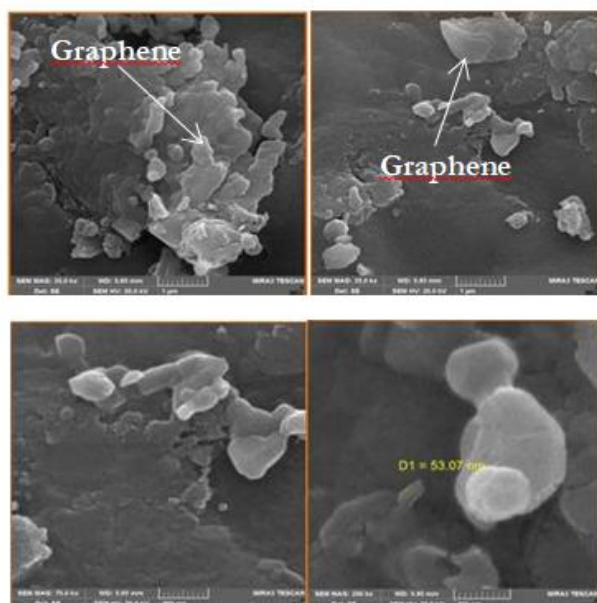


Figure 7. show SEM images for Gr2 sample

Graphite consists of many stacks of layers while exfoliated graphene consisted of submicrometre sized layered graphite. FESEM images proved the changes in the morphology, formation of high-quality

graphene nanosheets assembled into large clusters of several tens of micrometers. Some destruction was observed, which means graphite layers are broken by NaCl electrolyte, and distinct agglomeration of graphene can be observed at the surface texture confirmed with [19]. The images show irregular, sheet-like flakes characteristic of exfoliated graphene. The flakes appear thin and layered, with visible stacking and wrinkling, non-uniform in size, indicating partial exfoliation, crumpled or folded, which is expected for few-layer graphene (FLG). The NaCl-assisted exfoliation provide sufficient ionic strength to weaken the van der Waals forces between graphene layers, enabling separation into thinner sheets.

Table 2 illustrate EDS analysis show elements concentration on surface of samples, starting graphite material show a higher (C/O) ratio (24.67), (C/O= 7.6) with low oxygen content in Gr2 indicating low oxidation, while Gr4 has (C/O=1.26), and Gr3 has (C/O= 4.6). Low carbon content and high concentration of Cl and Na can be seen in both no rinsing samples Gr2 and Gr4, while high carbon content and low concentration of Cl and Na observed in rinsing Gr3, this behavior may be due to rinsing process.

Table 2. EDX analysis for samples

Sample	Wt%				C/O ratio
	C	O	Na	Cl	
Graphite	95.48	3.87	0	0	24.67
Gr2 not rinsing	39.93	5.25	20.8	31.62	7.6
Gr3 rinsing	73.98	16.16	3.12	3.16	4.6
Gr4 not rinsing	28.27	22.30	20.2	28.54	1.26

For graphite material analysis refer to very high carbon content reflects purity of the graphite, minimal oxygen indicates very low oxidation, and no Na or Cl, as expected. Gr2 sample (not rinsing) appear very low carbon content (only ~40%), high Na and Cl content (~52% total), moderate oxygen content (5.25%). C/O ratio drops drastically from 24.67 $\rightarrow$ 7.6 due to decreases of carbon content.

Gr3 (rinsing) Carbon significantly increases after rinsing. Na and Cl drop dramatically to ~3% each. Oxygen increases sharply to 16.16%. C/O ratio decreases to 4.6 (even lower than Gr2). Rinsing effectively removes most NaCl, confirming a successful washing step. The higher oxygen content implies oxidation of surface during exfoliation (mechanical, sonication, ionic interaction). Functional groups may be formed due to water exposure, shear forces, or NaCl interaction.

Massive NaCl retention in Gr4 sample because it was not rinsed. Unusually high oxygen content due to severe surface oxidation during exfoliation, absorption of moisture/surface oxygen on NaCl particles. C/O ratio near 1 refer to highly oxidized of the carbon surface.

Figure 8 refer to SEM/EDS analysis, oxidant states have been increased with increasing concentration of NaCl by formation of oxygen groups during exfoliation. The ablation of graphite electrodes in different NaCl concentration generated graphene with different densities of oxygen functionalities groups, and proved that the electrochemical process is advantageous by controlling its parameters to reached the optimum material.

Quantitative EDS data (Table 2) included carbon recovery efficiency was 39.93 wt% in Gr2 , 73.98 wt% in Gr3 and 28.27 wt% in Gr4. analysis reveals that rinsing reduces NaCl contamination by approximately 88% (from ~52 wt% in Gr2 to ~6 wt% in Gr3), while simultaneously increasing the carbon content by ~85%.

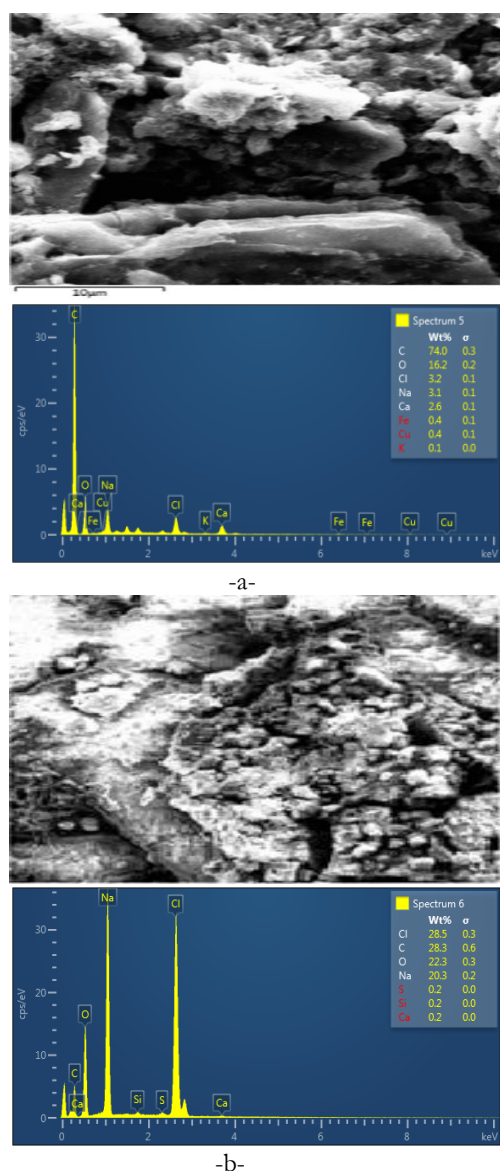


Figure 8. EDS spectra of : a-Gr3, b-Gr4

3.5 Raman Spectroscopy

Raman spectroscopy display better specificity than spectroscopy of UV for identifying the graphitic forms of the carbon and study the defects after reduced by sunlight. D-band refer to the presence of disorder in sp^2 -hybridized carbon systems, G-band evaluates stretching of C-C bonds in graphitic materials, 2D band confirming the formation of multi-layer graphene with defects.

Figure 9 refer to Raman spectrum obtained on the samples, main features D, G, 2D observed in Gr2 at D ($\approx 1360 \text{ cm}^{-1}$), G ($\approx 1611 \text{ cm}^{-1}$), 2D ($\approx 2733 \text{ cm}^{-1}$), in Gr3 at D ($\approx 1349 \text{ cm}^{-1}$), G ($\approx 1592 \text{ cm}^{-1}$), 2D ($\approx 2726 \text{ cm}^{-1}$) bands, while for Gr4 specimen at D ($\approx 1360 \text{ cm}^{-1}$), G ($\approx 1597 \text{ cm}^{-1}$), 2D ($\approx 2840 \text{ cm}^{-1}$) bands. In comparison with previous studies, Drabinska [25] approached that 2D (2700 cm^{-1}), G (1590 cm^{-1}), defect-related D (1350 cm^{-1}) bands.

Figure (9a) for Gr2 Confirms the presence of graphitic (sp^2 -hybridized) carbon, minimal doping or strain and typical few-layer graphene or partially exfoliated graphite. D band arises from defects, edges, vacancies, functional groups, or disorder in the graphene lattice. High D-band intensity refer to nanocrystalline domains, oxidation during exfoliation, increased edge density from flake size reduction, surface functionalization during contact with NaCl and/or rinsing.

Figure (9b) for Gr3, G band refer to carbon lattice is largely intact; sample contains graphitic layers, with respect to D band, exfoliation process produced small flakes and introduced lattice imperfections. Figure (9c) refer to Raman analysis for Gr4 sample, it is the same as for Gr2 sample. Chemical change of graphite to graphene results in a decrease in the ID/IG ratio refer to fewer defects and functional, in quantitative comparison for Raman analysis with reported values in the literature review, present work appear ID/G = 0.92-0.95, while ID/G value for reduced graphene oxide was 1.04 adopted from [3].

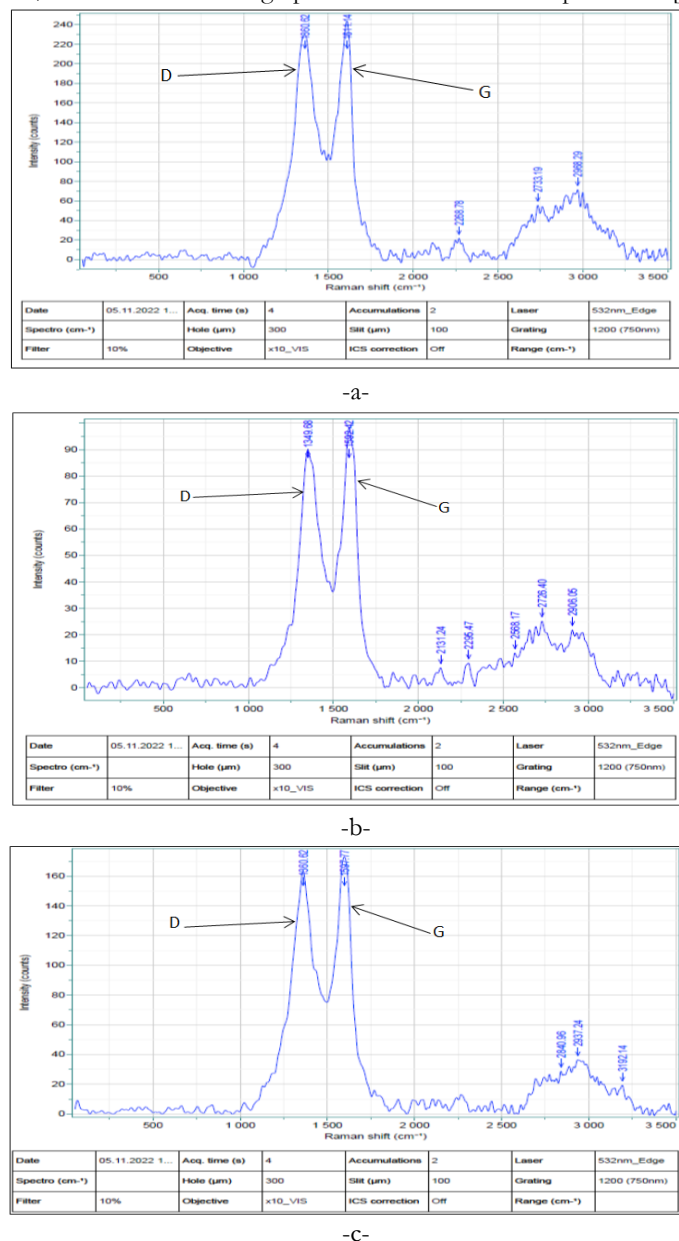


Figure 9. Raman spectra of: a-Gr2, b-Gr3, c-Gr4

Table 3. Raman shift, peaks intensities, I_D/I_G values

Sample	Raman shift			Intensity			I_D/I_G
	D	G	2D	D	G	2D	
Gr2	1360	1611	2733	230	242	55	0.95
Gr3	1349	1592	2726	90	97	25	0.92
Gr4	1360	1597	2840	164	173	27	0.94

The ratio (I_D/I_G) of the samples compared in table 3 and used to estimate number of graphene layers. In this study, graphene material produced was multilayers of graphene that adopted from values of ratio (I_D/I_G). Drabinska et al. have been reached that the increasing of scattering efficiency due to decoration of NaCl

nanoparticles with existing defects (grain boundaries and vacancies), and creation of on-site defects caused by this decoration [25] [26].

In addition to its role in exfoliation process, NaCl used in previous studies as corrosion solution due to the presence of ions when dissolved in distillation water [27][28].

ID/IG ratios, which are quantitative indicators of defect density, 0.95 for Gr2, 0.92 for Gr3 (lowest defects), and 0.94 for Gr4. Quantitatively, Gr3 exhibits the lowest defect density, indicating that rinsing not only removes residual NaCl but also mitigates excessive defect formation. All samples show $ID/IG < 1$, confirming multilayer graphene with fewer defects compared to reduced graphene oxide ($ID/IG \approx 1.04$ – 1.15 reported in literature).

In comparison with previous studies, Shokry et. al [29] chemically convert graphene from natural graphite by using modified Hummer process and approached that RGO prepared by this method contain 88.49% Atomic C (%), and 11.51 Atomic O (%), with respect to raman analysis, Shokry et. al approached that G band shifts to 1594 cm^{-1} . The lowered graphene oxide D/G intensity ratio is 1.15, which is somewhat less than the graphene oxide D/G intensity ratio of 1.37.

4. Conclusions

In this work, multilayer graphene material was successfully prepared by NaCl - assisted electrochemical exfoliation process followed by sunlight-induced photochemical treatment. The use of NaCl as a neutral electrolyte give a simple, low-cost, and environmentally benign route for graphene synthesize compared with acidic or alkaline electrolytes. NaCl promoted intercalation ions of Cl^- and OH^- into graphite layers, leading to anodic delamination and mitigating excessive oxidation of lattice of the graphene.

UV-Vis spectroscopy revealed a characteristic π - π^* transition around $\sim 230\text{ nm}$, with the disappearance of the shoulder peak at higher concentrations of NaCl indicating thicker multilayer graphene, larger conjugated sp^2 domains, and reduced oxygen functionalities. FTIR analysis confirmed successful exfoliation and moderate functionalization, showing limited oxygen-groups and evidence of C-Cl bonding, which supports the proposed role of chloride ions during exfoliation and photochemical processes. Particle size analysis proved that graphene sheets with average grain sizes of 4 – $9\text{ }\mu\text{m}$, and increasing of grain size with applied voltage but decreasing at higher NaCl concentration (0.2 M), the change of grain size may be due to restacking and oxidation effects.

FESEM images showed thin, wrinkled, and crumpled sheet-like morphologies characteristic of few- to multilayer graphene, while EDS results highlighted the strong dependence of C/O ratio on NaCl concentration and post-rinsing treatment. Lower NaCl concentrations and proper rinsing yielded graphene with relatively low oxidation, whereas higher NaCl concentration led to increased oxygen content and salt residue. Raman spectroscopy further confirmed the formation of multilayer graphene through the presence of D, G, and 2D bands, with ID/IG ratios (0.92 – 0.95) indicating moderate defect density and fewer defects compared with chemically reduced graphene oxide reported in the literature. The method offers promising route for large-scale graphene production for energy, electronic, and functional nanomaterial applications. Broader implications and future perspectives for NaCl-assisted electrochemical exfoliation approach in characters of the process: scalable, low-cost, and environmentally friendly pathway for graphene production and eliminates the need for harsh chemicals, as well as large-scale and continuous manufacturing. The obtained multilayer graphene, with controlled defect density and micrometer-scale lateral size, is well suited for practical applications. The structural characteristics of the synthesized graphene, micrometer-scale lateral dimensions, moderate defect density, and low

oxidation—are particularly advantageous for energy storage applications, where high electrical conductivity and accessible surface area are essential. In addition, the controllable surface functionality arising from chloride and oxygen groups enhances the suitability of the material for chemical and electrochemical sensing platforms. The produced graphene is also a strong candidate for polymer and structural composites, offering improved reinforcement efficiency at low filler loadings.

Future research should focus on process optimization, electrolyte recycling, and systematic yield analysis, and integration into device-level applications. Such efforts will facilitate the transition of NaCl-assisted electrochemical exfoliation from laboratory-scale synthesis to industrial graphene manufacturing. The multilayer structure, combined with surface defects and residual functional groups, can enhance charge storage capability and electrochemical activity in supercapacitors and battery electrodes. Compared with chemically oxidized graphene, the relatively low defect density preserves electrical conductivity, which is critical for high-rate performance. Also, for sensing applications, the presence of edge defects and functionalized sites facilitates strong interaction with target analytes, enabling improved sensitivity and selectivity. The tunable oxidation level achieved by adjusting NaCl concentration provides a pathway to engineer graphene surfaces for specific sensing environments.

5. Acknowledgment:

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