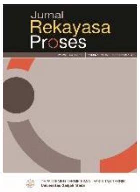
JURNAL REKAYASA PROSES
Review / Vol. 14, No. 1, 2020, pp. 8-18

Journal homepage: http://journal.ugm.ac.id/jrekpros



Change of Graphene with Various Strategies for Photocatalytic Applications: A Review

Won-Chun Oh
Department of Advanced Materials Science & Engineering, Hanseo University, Chungnam 356-706, South Korea
*Corresponding author: wc_oh@hanseo.ac.kr

(Submission: 23 February 2019; Revision: 8 August 2019; Acceptance: 16 August 2019)

ABSTRACT

Because of its novel molecular 2D structure and momentous physicochemical properties, graphene has been started a whirlwind of the investigation into its optical, electronic, thermal, and mechanical properties. Specifically, a lot of considerations have been pulled in to investigate graphene and graphene composites for photoelectrochemical applications. Many works have been done to synthesize novel graphene-based materials for applications in photoelectrochemistry, such as photoelectrochemical sunlight-based cells, photocatalytic disintegration of natural contaminations, and H_2 production. In this article, we abridge the condition of research on graphene-based materials for photoelectrochemistry. The prospects and further improvements in this energizing field of graphene-based materials are additionally discussed.

Keywords: graphene; H_2 evolution; photocatalytic

ABSTRAK

Karena struktur 2D dan keunggulan karakteristik fisika-kimia, graphene *telah mulai diselidiki secara menyeluruh terhadap sifat optik, elektronik, panas, dan mekanik. Secara khusus, focus dipelukan untuk menyelidiki* graphene *dan komposit* graphene *untuk aplikasi fotoelektrokimia. Banyak studi dikerjakan untuk membuat material baru berbasis graphene untuk aplikasi fotoelektrokimia seperti* photoelectrochemical sunlight-based cells, *fotokatalitik untuk penghilangan kontaminan, dan produksi* H_2*. Pada artikel ini akan disumarisasikan penelitian-penelitian terkait material berbasis* graphene *untuk aplikasi fotoelektrokimia. Harapan dan perkembangan aplikasi penggunaan material berbasis* graphene *juga didiskusikan.*

Kata kunci: *graphene;* evolusi H_2; fotokatalitik

DOI: 10.22146/jrekpros.43765

e-ISSN 2549-1490 p-ISSN 1978-287X

1. Introduction

Graphene's extraordinary characteristics invest graphene with favorable electromechanical properties. In any case of utilization, graphene is tested on the issues of creation, stockpiling, and also handling. Hence, adjustment and modification of graphene have pulled within broad intrigue. We outline the systems for compound modification of graphene, the impact of alignment, and the applications in different territories. As a rule, substance adjustment can be accomplished by utilizing either covalent or noncovalent collaborations (Geim and Novoselov, 2007). Covalent changes frequently decimate a portion of the graphene conjugation framework, bringing about trading off a part of its properties. Accordingly, we focus our study on the noncovalent change approaches, such as p – p stacking and van der Waals forces, because the noncovalent alterations conserve the regular arrangement and properties (Novoselov et al., 2004). It is also necessary to address the difficulties related to the creation, preparation, and execution improvement. Future viewpoints for the generation of the graphene within a vast amount with fewer imperfections and lower finer conditions are examined alongside the control of graphene's electromechanical and different properties (Lightcap and Kamat, 2013; Biswas and Oh, 2019; Oh et al., 2019).

The initial examination into delivering graphene has primarily centered on graphite or graphite oxide. The extensively utilized technique to orchestrate graphene in the substantial range is the Hummers strategy that includes oxidation– decrease mechanism, wherever oxidation yields graphene oxide (GO) against graphite along with the decrease changes over the graphene oxide to graphene within sight of a reductant, for instance, hydrazine or sodium borohydride (Zhang et al., 2013). The important thing is that the decrease of graphene oxide will evacuate most of the oxygen-containing useful ties, for example, hydroxyl, carboxylic acid, and epoxy gatherings. Thus, decrease procedure provides sensibly hydrophobic graphene sheets, whichever turned to total permanently. The permanent accumulation of GO utilizing p–p stacking would significantly frustrate owned creation, stockpiling along with preparing. In this way, adjustment and functionalization of GO through a change of the material is essential with the end goal to maintain a strategic distance from the undesired conglomeration and augment its utilization. The notable thing is, the properties of GO start to its arrangement (Liu et al., 2013). Subsequently, insurance of the graphene structure is the need for any alteration. The strategies for adjusting graphene utilizing the noncovalent or covalent techniques along with talk about its favorable circumstances and detriments —the properties and utilizations of the adjusted graphene substances. Mechanical peeling, warm testimony, oxidation of graphite, and fluid stage shedding of graphite are the for the most part, now and again utilized strategies to incorporate graphene (Yang et al., 2013). The Visit and Dai bunches have likewise effectively unfastened carbon nanotubes to get nanoribbons.

Also, Zhang et al. (2010) delivered unadulterated mono-layered graphene sheets dependent upon a self-gathered layout of surfactants. Mechanical shedding, along with warm testimony strategies, similar to concoction vapor affidavit, is favored for the readiness of superb, extensive estimated and deformity free graphene sheets, however, in the extremely constrained amount at extant. N-doped graphene among n-type conduct was likewise accomplished through Liu along with collaborators utilizing a concoction vapor affidavit strategy (Kuila et al., 2017). To get ready graphitic Nanoplatelets using an anionic polymer as a surfactant through the decrease of lasting fluid scatterings of graphite oxide Nanoplatelets, empowering the improvement of the readiness of graphene–polymer composites, in 2005 Stankovich along with colleagues built up this strategy (Ma et al., 2012). The graphitic Nanoplatelets arranged by themselves are monolayer graphene sheets, as controlled by AFM investigation. Graphene sheets could be delivered within an extensive range utilizing aqueous science strategy that, for the most part, includes oxidation–decrease process (Du and Cheng, 2012). The oxidation procedure may help the peeling of GO to the extended graphite along with the decrease procedure recoups the conductivity of GO by reestablishing an in-sheet conjugated arrangement. In any case, the graphene sheets arranged through these oxidation–decrease techniques generally hold a huge plane of imperfections and have wild geometrical aspects because of brutal oxidation situations. As reported, the majority of those techniques have a few inconveniences, such as the client's familiarity with picking an arrangement strategy for particular applications. Oxidation-reduction strategies have the preferred standpoint that they can create graphene in a moderately substantial amount (Kuilla et al., 2010). In any case, oxidation–decrease techniques, for the most part, require unforgiving response conditions, and the graphene sheets delivered are generally little and hold numerous deformities because of the extreme oxidation condition. In this way, other gentle manufactured techniques are required and are relied upon to be created. Graphene has discovered utilization in catalysis as long as steady arrangement, as well as because the electrical and thermal conductivities can impact the electronic properties of a surface-bound metal impetus, giving a chance to tune material properties.

2. Research Methodology

Utilizing appropriate metallic planes at high temperatures chemical vapor deposition (CVD) is a good strategy used to deliver single or limited coating of graphene on a substantial scale, as shown in Figure 1 (Iwan and Chuchmała, 2010; Pumera, 2010).

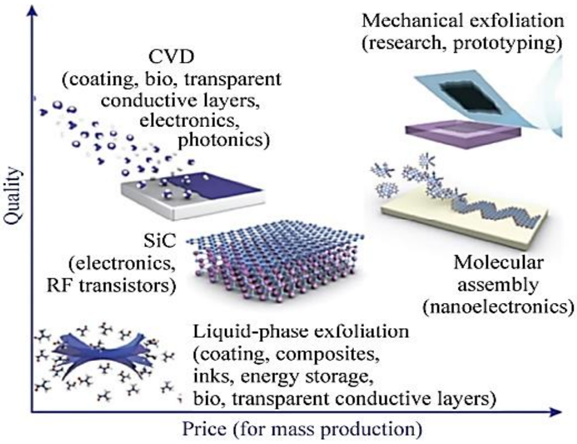


Figure 1. Methods for mass-producing graphene's in terms of size, quality and price for particular applications (Copyright Nature Publishing Group. Reprinted from Novoselov et al., 2012).

In this process, the carbon is broken up in a metallic substrate previously, accelerated on the substrate through cooling. Under vacuum condition (10^{-3} Torr) and below 1000 °C, with a deteriorated hydrocarbon gas, a Ni substrate was set in a CVD chamber (Pumera, 2011). At a moderately small temperature like the carburization, the procedure starts with a couple of carbon particles fusing into the Ni substrate. Graphite oxide can incorporate by rusting graphite utilizing solid compound oxidizing operators in exceptionally thought inorganic acids. Graphite oxide is, for the most part, created through a best down course, which uses concentrated H_2SO_4 alongside the accompanying: (1) seething nitric acid and a $KClO_3$ oxidant (Maiti et al., 2014); (2) Concentrated nitric acid and a $KMnO_4$ oxidant (Areshkin and White, 2007); or (3) concerted phosphoric corrosive with $KMnO_4$ (Visit) (Li et al., 2010). Likewise, warm peeling and decrease of graphite oxide create great quality graphene, or, in other words, thermally lessened graphene (TRG).

3. Results and Discussion

3.1 Covalent modification of graphene

As examined before, graphene surfaces can be artificially changed utilizing either covalent or noncovalent strategy. Covalently appending distinctive functionalities on top of graphene planes generally happens over oxygen bonds, which are classified as "oxygenated useful gatherings" or basic π-π systems. Besides, the nearness of corrosive carboxylic gatherings at the ends and epoxy/hydroxyl bunches on the basal plane of graphene and graphene oxide are utilized to tailor the surface usefulness of graphene surfaces. In the accompanying areas, we audit the real courses produced for covalently altering graphene.

3.2 Organic functionalities on the pure graphene with covalent connection

The development of graphene-based nanocomposite materials, the scattering of graphene sheets in natural diluents, is a basic advance. Henceforth, covalent adjustment of graphene with different inherent functionalities is the way to accomplish significant dispersion. Graphene (G) has been adjusted utilizing double overall highways: (1) responding to the oxygen gatherings of run through natural utilitarian gatherings and (2) joining permitted immaculate graphene C–C links through radicals or dienophiles. The most appealing natural types for the response with sp2 carbons in graphene are sans natural radicals and dienophiles, because of past effort on fullerene and carbon nanotubes (see Figure 2). Generally, these species are transitional responsive parts created under specific conditions within sight of the graphene.

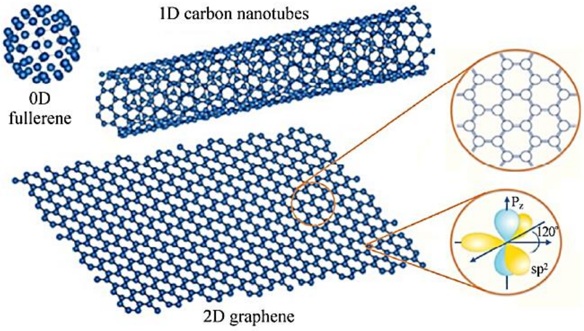


Figure 2. Low-dimensional carbon allotropes: Fullerene (0D), carbon nanotube (1D), and graphene (2D) and atomic and electronic structure of graphene wherein carbon atoms are arranged in a honeycomb lattice having sp2 hybridization (Copyright Elsevier Ltd. Reprinted from Soldano et al., 2010).

3.3 Adding free radical to the graphene's sp^2 carbon atoms

Free radical responses are the absolute most significant normal responses utilized with graphene nano-materials toward advance broaden the group hole and balance dissolvability. To this objective, from diazonium salts and benzoyl peroxide radicals be able to create. By responding with the sp^2 carbon particles of the graphene, at lifted temperatures, diazonium salts create exceedingly receptive free radicals that can frame a covalent bond. Visit and colleagues utilized this strategy to change graphene utilizing nitro phenyl bunches, as shown in Figure 3 (Schwierz, 2010). By changing the response time; more extended occasions create graphene with lower conductivity, the conductivity of the graphene sheets can be precise. Besides, controlling the band hole, possibly making a semiconductive material dependent on nano-materials, the response time and level of alteration can be utilized.

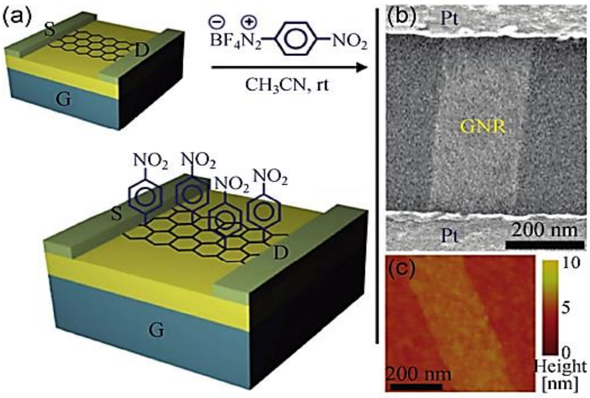


Figure 3. Chemical doping of graphene with 4-nitrophenyl groups: (a) Schematic representation; (b) SEM image of a graphene nanoribbon (GNR) between Pt electrodes; (c) AFM image of a fragment of a graphene monolayer (Copyright American Chemical Society. Reprinted from Maiti, 2014).

X-beam photoelectron spectroscopy (XPS) was utilized to confirm the covalent connection of the 4-nitrophenyl gatherings to the graphene surface as shown in Figure 4 (base). XPS range of the functionalized graphene contained two tops with restricting energies at 406 and 400 eV (N1s), relating to the nitrogen of the NO_2 and the in part decreased nitrogen of the item, individually. Besides, diazonium salts have been utilized to functionalize synthetically or thermally changed over graphene. Through micromechanical cleavage from mass graphite, and epitaxial graphene, the single graphene sheets were gotten (Ramanathan et al., 2008). As of late, hydroxylated aryl bunches were covalently joined to graphene through a diazonium expansion response (Schniepp et al., 2006). A while later, the hydroxylated aryl locales were associated with polymer chains (polystyrene) utilizing a nuclear exchange radical polymerization (ATRP). Initiators, catalyzing the covalent connection of the polymer to the graphene surface is characteristic of the ATRP of styrene, diazonium radicals. Feng et al. likewise arranged diminished graphene oxide–azobenzene (RGO–AZO) crossbreeds using covalent functionalization utilizing permitted extreme diazotization aimed at extended haul sun oriented thermal capacity.

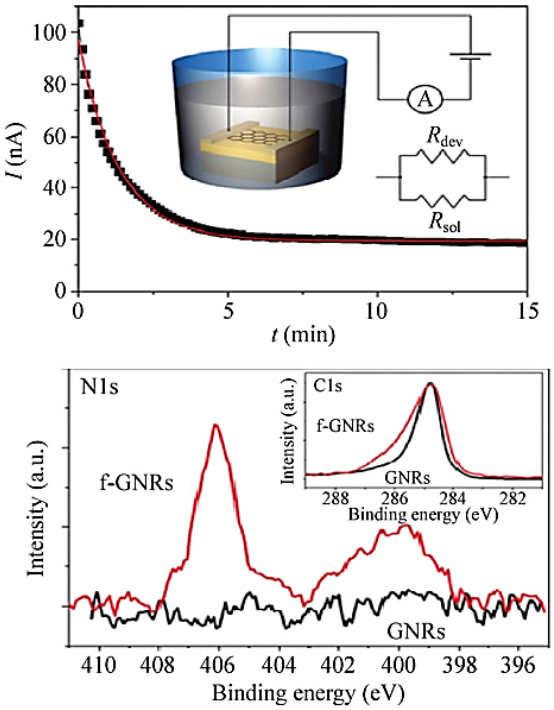


Figure 4. Time (t) vs. current (I) performance of a graphene diazonium salt: (top) Schematic representation of a device consisting of two parallel resistors derived from the graphene and the solution, and (bottom) XPS spectra of the GNRs: N1s and C1s before and after the chemical modification (f-GNRs) (Copyright American Chemical Society. Reprinted from Maiti et al., 2014).

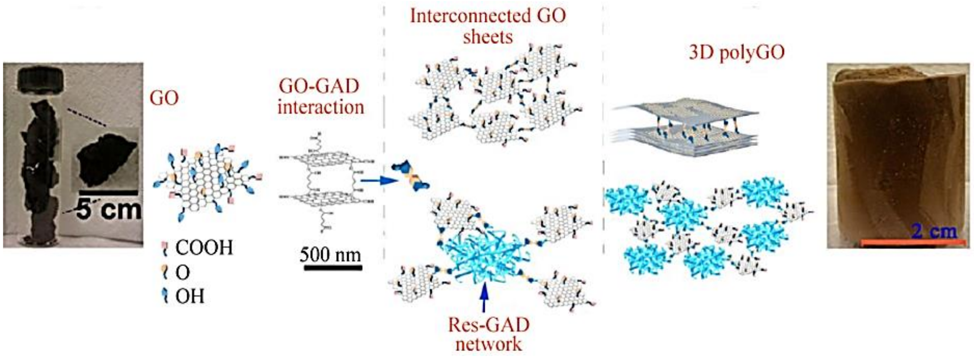


Figure 5. Schematic of the poly-GO synthesis from GO powder. Photograph showing the GO powders (left); Schematic of the linkage between GAD (yellow) and two different OH groups (blue) (middle); Lyophilization (freeze-drying) of cross-linked solution forms solid macroscopic structures with controllable shapes and sizes (right) (Copyright American Chemical Society. Reprinted from (Areshkin and White, 2007).

Xu et al. (2008) changed graphene outward through phenyl bunches over a free-radical expansion. The expansion of the phenyl bunch was confirmed through the proximity of a thick D band at 1,343 cm^{-1}. The D-groups speak to the development of sp^3-hybridized carbon iotas in the basal plane of graphene made when the phenyl bunches were included. The resulting materials might be utilized to develop a FET gadget. In this gadget, due to the extra sp^3 carbon molecules made while joining the phenyl gatherings, a decline in conductivity was seen. As of late, Zhang et al. (2010), to substance functionalization utilizing aryl diazonium salts, examined the bodily and electrical structures and possessions of double-layer graphene exposed (Figure 5). The trademark alterations were seen in the Raman spectra and conductive AFM when double-layer graphene was utilized.

3.4 Covalent adjustment of graphene using dienophiles

The sp^2 carbons in graphene can react with dienophiles, despite permitted extra ordinary's reactions using sp^3 hybridized carbon particles. This dienophile has been cast-off to functionalize carbon nanostructures, for instance, fullerenes, nanotubes, onions, nano horns, and their backups can be associated in a couple of domains, for instance, composites, biotechnology, and hardware, steady transport and sun situated cells (Liu et al., 2008). These social occasions can be joined symmetrical to the graphene surface by including the azomethine ylide forerunners. The azomethine ylide was molded by uniting 3,4-dihydroxybenzaldeyde with sarcosine. This reaction adds a hydroxyl social affair to the graphene sheet, attractive its dispersibility in polar diluents, for instance, ethanol and N, N-dimethyl formamide (DMF). This change assembles the Raman power of D band of G band (I D / I G) the extent and apex growing. These movements rise out of functionalizing the graphene outward by growing the number thickness of the sp^3 planar carbon particles. Likewise, Niyogi et al. (2006) secondhand Cu-catalyzed Huisgen 1,3-dipolar cycloaddition reactions to couple graphene drop with a conjugated polymer (poly[(9,9-dihexylfluorene)- co-alt-(9,9-bis-(6-azidohexyl)fluorene)] (PFA)).

3.5 Noncovalent modification of graphene

In view of this segment, we should audit a few techniques created to frame noncovalent associations among graphene and other atomic species. Specifically, the noncovalent organization of graphene, including $\pi - \pi$ communications, hydrophobic fascination amid a surfactant along with graphene, and hydrogen holding cooperation, are checked. Additionally, the practical properties of the materials are plot and their prospects talked about in the specific cases. The noncovalent interaction among graphene and natural atoms is noteworthy because methodologies alter the graphene exterior beyond decreasing the exceptional properties of the double-dimensional sp^2 organize (Bai et al., 2009; Xu et al., 2009). Since inconspicuous alteration in the electronic attributes to the π-frameworks could induce auxiliary disturbance of graphene sheets because of properties (Georgakilas et al., 2010; Hirsch et al., 2013). In this way, surfactants change the noncovalent surface of graphene. Ionic fluids, either large scale particles, have generally been utilized to acquire very steady scatterings of single graphene sheets in the twain, watery and natural media without modifying the auxiliary trustworthiness of graphene. The point by point discourse of the noncovalent alteration of graphene surfaces utilizing different substance collections is introduced in the accompanying sections.

3.6 Polynuclear aromatic rings

Seeing the excellent partiality for $\pi - \pi$ cooperation and included usefulness, the particular sorts of sweet-smelling particles are now and again utilized to scatter graphene sheets in natural watery media. Specifically, fragrant dimers of benzene, naphthalene, anthracene, and pyrene, which are examples of polyaromatic hydrocarbons that are functionalized with adaptable or potentially polar side chains, were viable. The pyrene moiety has a solid liking toward the basal plane of graphite. Green and associates

Liu et al. (2012) examined a few functionalized pyrene subsidiaries (Figure 6), and these species could balance out mono- and few-layer graphene chips within fluid scatterings.

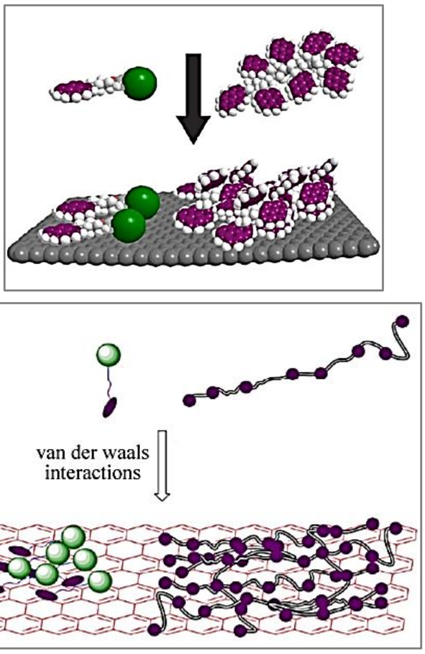


Figure 6. Schematic of graphene noncovalent functionalization using polymers and small-molecule adsorbates (Copyright American Chemical Society. Reprinted from Novoselov et al., 2012).

Furthermore, the graphene produced over this strategy is substantially bigger than that of regular nanomaterial stabilizers, such as surfactants or polymers. This system, because of adjustment from pyrene subsidiaries, was examined by concentrate on different parameters. The creators noticed that an adequate distinction amid the extremity of the dissolvable and the stabilizer is needed for adsorption on the graphene exterior.

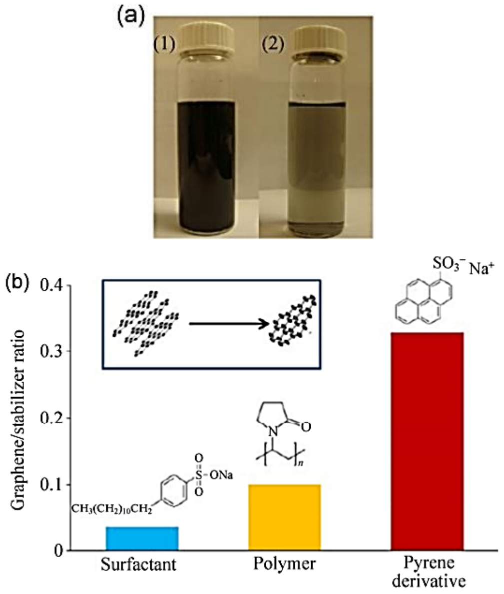


Figure 7. (a) Dispersions of (1) Py-SASS and (2) Py(SO_3)$_4$ functional graphenes and (b) a comparison of the different functionalities during graphene dispersion (Copyright American Chemical Society. Reprinted from Green and Hersam, 2009).

The job of the practical gatherings on the pyrene subordinates amid the adjustment procedure was additionally investigated; when driving the adsorption of stabilizers onto the graphene layers, then the useful gatherings with higher electronegativities are more productive (Figure 7). Mullen and collaborators Park and Yan (2013) utilized the sodium salt of pyrene-1-sulfonic corrosive (PyS) as an electron contributor, and the sodium salt of 3,4,9,10-perylenetetracarboxylic diimide bisbenzene-sulfonic corrosive (PDI) as an electron acceptor. The mentioned creators exhibited that PyS and PDI have a vast planar sweet-smelling organization that emphatically grapple them onto the hydrophobic exterior of graphene sheets by π– π collaborations beyond upsetting the electronic union of graphene. Also, the polyaromatic part interfaces with the graphene by π– π stacking, when the contrarily charged portion (corrosive) improves that dissolvability of the sheet, ruining re-accumulation. So also, Quintana et al. (2013) utilized aqua-solvent 1-pyrenebutyrate (PB) as a stabilizer while getting ready permanent fluid scatterings of graphene nanoplatelets.

4. Conclusions

Given this survey, all of us have condensed the ongoing effort in the quickly developing field of graphene look into within a particular accentuation upon concoction change. Regardless of having a few fascinating properties, the capability of graphene for different applications is restricted because of challenges experienced amid physical taking care. Various endeavors have been built to balance out graphene by substance alteration. It can be covalent or noncovalent. Covalent capacity allocation principally includes traditional natural responses, for example, diazonium pairing, cycloaddition, replacement, and different reactions. Noncovalent methodologies use π–π communications. These tied down functionalities improve the scattering of graphene in solvents or polymer lattices when including advanced useful properties, uncovering different applications for graphene in various areas. Be that as it may, a couple of concerns, such as the associations between the oxidative garbage and practical gatherings amid noncovalent alteration, should even now be tended. Notwithstanding the current abundance of learning in graphene functionalization, we foresee that the more up to date parts of the compound alterations. Additionally, investigations of graphene sensation along with engineered control, and also enhanced portrayal apparatuses would create the progression of novel materials with very particular activities and huge latent for focused function. We have condensed these ongoing techniques received amid the synthetic change of graphene along with their effect on the properties of graphene and also advanced exercises that are given by them. Area of functions such as gas sensors, biosensors, adsorption of harmful gases, vitality stockpiling, catalysis, and polymer nanocomposites, should profit the most from graphene utilization.

References

Areshkin, D. A., and White, C. T., 2007, Building blocks for integrated graphene circuits, Nano Lett., 7, 3253–3259.

Bai, H., Xu, Y. X., Zhao, L., Li, C., and Shi, G. Q., 2009, Non- covalent functionalization of graphene sheets by sulfonated polyaniline, Chem. Commun., 45, 1667–1669.

Du, J. H., and Cheng, H. M., 2012, The fabrication, properties, and uses of graphene/polymer composites, Macromol. Chem. Phys., 213, 1060–1077.

Biswas, M. R. U. D., and Oh, W.C., 2019, Comparative study on gas sensing by a Schottky diode electrode prepared with graphene–semiconductor–polymer nanocomposites, RSC. Adv., 9, 11484-11492

Geim, A. K., Novoselov, K. S., 2007, The rise of graphene, Nat. Mater., 6, 183–191.

Georgakilas, V., Bourlinos, A. B., Zboril, R., Steriotis, T. A., Dallas, P., Stubos, A. K., Trapalis, C., 2010, Organic functionalisation of graphenes, Chem. Commun., 46, 1766–1768.

Green, A. A., and Hersam, M. C., 2009, Solution phase production of Solution Phase Production of Graphene with Controlled Thickness via Density Differentiation, Nano Lett., 9 (12), 4031-4036.

Hirsch, A., Englert, J. M., Hauke, F., 2013, Wet chemical functionalization of graphene, Acc. Chem. Res., 46, 87–96.

Iwan, A., Chuchmała, A., 2012, Perspectives of applied graphene: Polymer solar cells, Prog. Polym. Sci., 37, 1805–1828.

Krishnamoorthy, K., Kim, G. S., Kim, S. J., 2013, Graphene nanosheets: Ultrasound assisted synthesis and characterization, Ultrason. Sonochem., 20, 644–649.

Kuilla, T., Bhadra, S., Yao, D. H., Kim, N. H., Bose, S., Lee, J. H., 2010, Recent advances in graphene-based polymer composites, Prog. Polym. Sci., 35, 1350–1375.

Kuila, T., Bose, S., Khanra, P., Mishra, A. K., Kim, N. H., Lee, J. H., 2011, Recent advances in graphene-based biosensors, Biosens. Bioelectron, 26, 4637–4648.

Li, S. L., Miyazaki, H., Kumatani, A., Kanda, A., Tsukagoshi, K., 2010, Low operating bias and matched input-output characteristics in graphene logic inverters, Nano Lett., 10, 2357–2362.

Lightcap, I. V., Kamat, P. V., 2013, Graphitic design: Prospects of graphene-based nanocomposites for solar energy conversion, storage, and sensing, Acc. Chem. Res., 46, 2235–2243.

Liu, Z., Robinson, J. T., Sun, X. M., Dai, H. J., 2008, PEGylated nanographene oxide for delivery of water-insoluble cancer drugs, J. Am. Chem. Soc., 130, 10876–10877.

Liu, J. Q., Tang, J. G., Gooding, J. J., 2012, Strategies for chemical modification of graphene and applications of chemically modified graphene, J. Mater. Chem., 22, 12435–12452.

Liu, J. Q., Cui, L., Losic, D., 2013, Graphene and graphene oxide as new nanocarriers for drug delivery applications, Acta Biomater., 9, 9243–9257.

Ma, H. M., Wu, D., Cui, Z. T., Li, Y., Zhang, Y., Du, B., Wei, Q., 2013, Graphene-based optical and electrochemical biosensors: A review, Anal. Lett., 46, 1–17.

Maiti, U. N., Lee, W. J., Lee, J. M., Oh, Y., Kim, J. Y., Kim, J. E., Shim, J., Han, T. H., Kim, S. O., 2014, 25th anniversary article: Chemically modified/doped carbon nanotubes & graphene for optimized nanostructures & nanodevices, Adv. Mater., 26, 40–67.

Maiti, U. N., Lim, J., Lee, K. E., Lee, W. J., Kim, S. O., 2014, Three-dimensional shape engineered, interfacial gelation of reduced graphene oxide for high rate, large capacity supercapacitors, Adv. Mater., 26, 615–619.

Novoselov, K. S., Geim, A. K., Morozov, S. V., Jiang, D., Zhang, Y., Dubonos, S. V., Grigorieva, I. V., Firsov, A. A., 2004, Electric field effect in atomically thin carbon films, Science, 306, 666–669.

Novoselov, K. S., Fal'ko, V. I., Colombo, L., Gellert, P. R., Schwab, M. G., Kim, K., 2012, A roadmap for graphene, Nature, 490, 192–200.

Niyogi, S., Bekyarova, E., Itkis, M. E., McWilliams, J. L., Hamon, M. A., Haddon, R. C., 2006, Solution properties of graphite and graphene, J. Am. Chem. Soc., 128, 7720–7721.

Oh, W.C., Nguyen, D.C.T., Ullah, K., Zhu, L., and Areerob, Y., 2019, Fabrication of CdO–graphene embedded mesoporous TiO_2 composite for the visible-light response and its organic dye remediation, Separation Science and Technology, doi.org/10.1080/01496395.2019.1602648

Park, J., Yan, M. D., 2013, Covalent functionalization of graphene with reactive intermediates, Acc. Chem. Res., 46, 181–189.

Pumera, M., 2010, Graphene-based nanomaterials and their electrochemistry, Chem. Soc. Rev., 39, 4146–4157.

Pumera, M., 2011, Graphene-based nanomaterials for energy storage, Energy Environ. Sci., 4, 668–674.

Quintana, M., Vazquez, E., Prato, M., 2013, Organic function- alization of graphene in dispersions, Acc. Chem. Res., 46, 138–148.

Ramanathan, T., Abdala, A. A., Stankovich, S., Dikin, D. A., Herrera-Alonso, M., Piner, R. D., Adamson, D. H., Schniepp, H. C., Chen, X., Ruoff, R. S., 2008, Functionalized graphene sheets for polymer nanocomposites, Nat. Nano- technol., 3, 327–331.

Schniepp, H. C., Li, J. L., McAllister, M. J., Sai, H., Herrera-Alonso, M., Adamson, D. H., Prud'homme, R. K., Car, R., Saville, D. A., Aksay, I. A., 2008, Functionalized single graphene sheets derived from splitting graphite oxide, J. Phys. Chem. B., 110, 8535–8539.

Schwierz, F., 2010, Graphene transistors, Nat. Nanotechnol., 5, 487–496.

Soldano, C., Mahmood, A., Dujardin, E., 2010, Production, properties and potential of graphene, Carbon, 48, 2127–2150.

Xu, Y. X., Bai, H., Lu, G. W., Li, C., Shi, G. Q., 2008, Flexible graphene films via the filtration of water-soluble noncovalent functionalized graphene sheets, J. Am. Chem. Soc., 130, 5856–5857.

Xu, Y. F., Liu, Z. B., Zhang, X. L., Wang, Y., Tian, J. G., Huang, Y., Ma, Y. F., Zhang, X. Y., Chen, Y. S., 2009, A graphene hybrid material covalently functionalized with porphyrin: Synthesis and optical limiting property, Adv. Mater., 21, 1275–1279.

Yang, Y. Q., Asiri, A. M., Tang, Z. W., Du, D., Lin, Y. H., 2013, Graphene based materials for biomedical applications, Mater. Today, 16, 365–373.

Zhang, J. L., Shen, G. X., Wang, W. J., Zhou, X. J., Guo, S. W., 2010, Individual nanocomposite sheets of chemically reduced graphene oxide and poly (N-vinyl pyrrolidone): Preparation and humidity sensing characteristics, J. Mater. Chem., 20, 10824–10828.

Zhang, J., Zhao, F., Zhang, Z. P., Chen, N., Qu, L. T., 2013, Dimension-tailored functional graphene structures for energy conversion and storage, Nanoscale, 5, 3112– 3126.