



## Application of graphene oxide in bio electrochemistry

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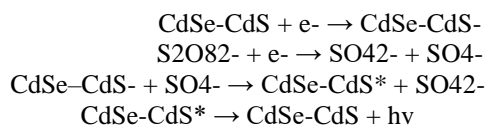
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### ABSTRACT

Graphene is a two-dimensional (2D) planar sheet of carbon atoms in a hexagonal configuration where the atoms are sp<sup>2</sup>-bonded [33]. Graphene sheets are formed by placing carbon atoms together. In a graphene sheet, each tetravalent carbon atom is connected to three other carbon atoms with three covalent bonds. These three links are on the same plane and the angles between them are equal to 120 degrees. In 2004, a group of physicists at the University of Manchester, led by Andre Geim and Kostya Novoselev, used a simple and very different method to produce graphene, leading to a revolution in the field. Using 3D graphite, they produced a single sheet (a monolayer of atoms) of it through a micromechanical layer-by-layer method. This method led to the easy production of high-quality graphene crystals with dimensions of more than one hundred micrometers. Graphene, this two-dimensional nanomaterial (2D) is the newest member of the family of multidimensional carbon materials, which includes fullerenes as zero-dimensional nanomaterials (0D), single-walled carbon nanotubes (SWNT) as one-dimensional nanomaterials (1D), and graphite as a three-dimensional material (3D). Graphene is a two-dimensional allotrope of carbon (one atom thick) with a honeycomb structure. In terms of strength, this material is one of the strongest materials known so far. This composition is the basic constituent of carbon nanotubes and large fullerenes.

### Introduction

The basis of this detection method is based on ECL, ECL is a type of luminescence produced during electrochemical reactions, or in other words, ECL is a light production method using electrochemical reactions to produce reactive species on the electrode surface [1]. whose possible mechanism is through the following relationships:



This cancer detection method has high sensitivity and selectivity, and its detection limit is equal to fgml-1 32. Studies show that this method has a lower detection limit compared to other methods, including the ESEIA method.

It is noteworthy that this method is not specific to the detection of lung cancer, but is also used to detect other types of cancer [2].

### Graphene

The two-dimensional structure of graphene has caused the appearance of unique physical and chemical properties in it, which include high Young's modulus (about 1100 GPa), high resistance to fracture (125 GPa), good thermal conductivity (about W/mK5000), high carrier mobility. In other words, high electrical conductivity (cm<sup>2</sup>/Vm 200,000), high specific surface area (calculated value: 2630 square meters per gram), high light transmittance (about 97.7%) and amazing transition phenomena such as the quantum Hall effect [3]. In recent years, a lot of research has been done to develop different methods of graphene production.

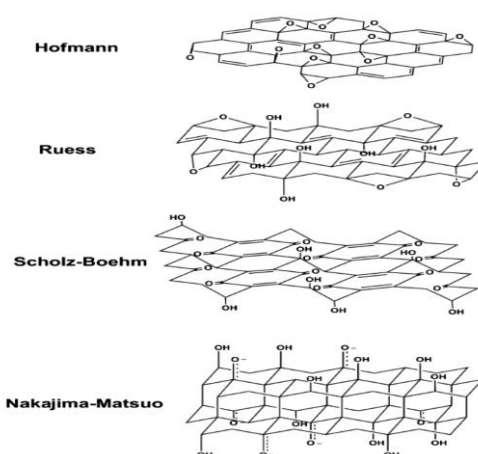
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Today, high-quality graphene synthesis is done through various methods such as chemical vapor deposition (CVD), interwoven growth on electrical insulating surfaces, and creation of colloidal suspensions and micromechanical layering of graphite [4].

### Graphene oxide

Graphene oxide (GO), which is one of the derivatives of graphene, consists of a two-dimensional atomic layer of  $sp^2$  hybridized carbon atoms with a hexagonal configuration, and there are  $sp^3$  hybridized carbon atoms attached to oxygenated functional groups. The most common method for layering graphite in order to produce graphene oxide is the use of strong oxidizing agents [5], as a result of which, by placing oxygenated functional groups in the structure of graphite, graphite oxide is obtained. The distance between two layers in graphite increases from 0.335 nm to about 0.625 nm in graphite oxide [6]. Graphite oxide is basically layered and creates single-layer graphene oxide sheets (with dimensions of several hundred nanometers to several micrometers) through the ultrasonic method. Determining the exact structure

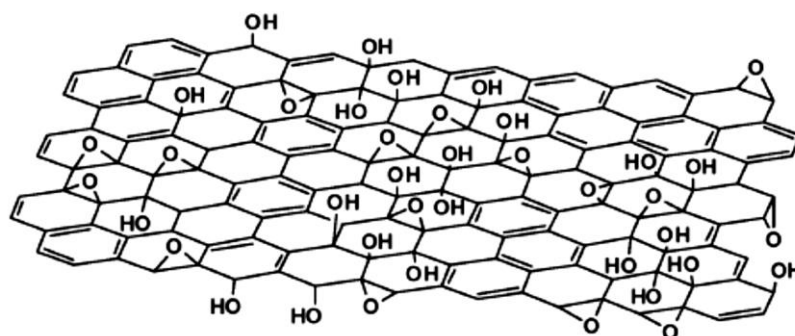
of graphene oxide is difficult, but it is obvious that graphene oxide is a continuous aromatic network of graphene to which the functional group of alcohols, epoxides, ketones, aldehydes and carboxylic acids are attached [7]. The exact chemical structure of GO has been discussed for many years, but until now, due to various reasons, no unambiguous structural model has been provided. Many early structural models of GO proposed regular networks composed of distinct repetitive units. The structure of Hoffmann and Holst includes epoxy groups distributed in all graphite sheets with the pure molecular formula of  $C_2O$ , and the Ross structural model presented in 1946 has changed the planar structure of GO to a structure with  $sp^3$  hybridization instead of the  $sp^2$  hybrid of Hoffmann's structural model. In this model, a quarter of cyclohexanes have epoxide in position one and three and hydroxyl group in position four [8]. In 1969, Schulz and Boehm proposed a model in which the ether and epoxide groups were omitted and after that, Nakajima and Matsu presented an interesting model based on lattice framework similar to poly (dicarbon monofluoride) ( $C_2F$ )<sub>n</sub>.



**Figure 1.** Proposed structural models for GO

The latest proposed GO model rejects the lattice model and focuses on the non-stoichiometric

amorphous structure. This model, which is the most famous structural model of GO, was presented by Lerf and Klinowski in 1998.

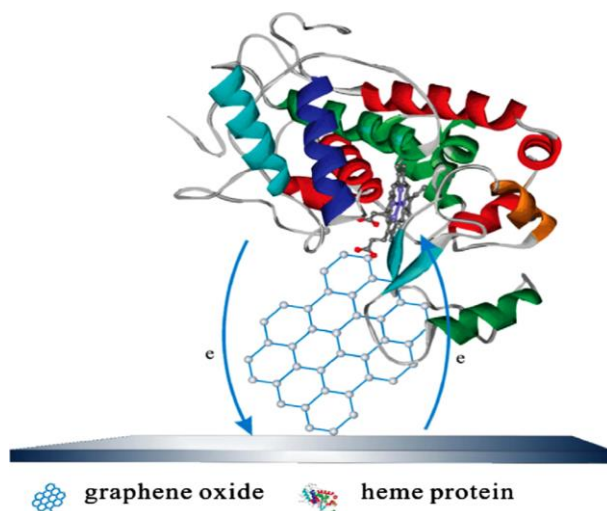


**Figure 2.** Lerf-Klinowski structural model

### Applications of graphene oxide

Graphene and chemically modified graphene (CMG) or in other words chemical derivatives of graphene are very suitable options for various applications such as energy storage materials, paper-like materials, polymer composites, liquid crystal instruments, mechanical oscillators, sensors and biological-medical applications [8]. Basically, the importance of GO is due to its fundamental physical and chemical structure, which causes its extraordinary chemical versatility and unusual physical properties. The chemical versatility of GO

stems from the oxygenated functional groups on its carbon structure, which enable relatively easy functionalization with organic molecules or biological structures through covalent or non-covalent bonding under mild conditions. The compatible effects resulting from the set of structures defined on the surface of GO as well as its optical, mechanical and electronic properties lead to the development of new multifunctional hybrid structures that have a high potential in cancer treatment [9].



**Figure 3.** Electrical connection of proteins by GO in electrochemistry.

### Application of graphene oxide in bio electrochemistry

Graphene has been successfully used in bio electrochemistry, it is a useful nanomaterial in Nano electronics due to its very high conductivity and unique surface properties such as very low thickness (one atom size) and irreversible surface adsorption of protein on the surface. Graphene-based materials can be used as an ideal surface for protein adaptation and facilitating protein electron transfer, during which GO causes an effective electrical connection between the electrode and redox centers of several metalloproteinase with heme groups, including cytochrome c, myoglobin, and horseradish peroxidase. The remarkable thing is that when proteins are adsorbed on the surface of oxidized graphene, they maintain their biological activity and coherent structure. This property predicts the wide application of protein-GO complex in the development of biosensors [10].

### Medical and biological applications of graphene oxide

The applications of nanomaterials are always limited due to their low solubility and stability in biological solutions, but GO is widely used in

biological and medical fields due to its hydrophilic (COOH) groups and hydrophobic flat surface. Apoptosis is a programmed cell death that in normal conditions causes the removal of old, damaged, extra and harmful cells in the body any disturbance in the process of apoptosis leads to a disease, among which cancer, autoimmune disorders, neurodegenerative disorders and heart failure can be mentioned.

Caspase 3 has been identified as a central mediator for the initiation and propagation of apoptosis. Yu and his colleagues identified its activation in living cells using graphene oxide-peptide Nano hybrid as an intracellular protease Nano sensor. The peptide probe was attached to GO using the hydroxylsuccinimide (EDC-NHS) coupling method and showed excellent solubility and stability in water and cell growth medium. During several experiments in the laboratory, the detection limit of (7.25) ngmL<sup>-1</sup> (~0.4 nM) has been obtained for caspase 3. Graphene oxide-peptide Nano hybrid was effectively directed into HeLa cells (cervical cancer cells) and the activation of caspase 3, which was stimulated by staurosporine (STS), was detected by the intracellular protease Nano sensor [11].

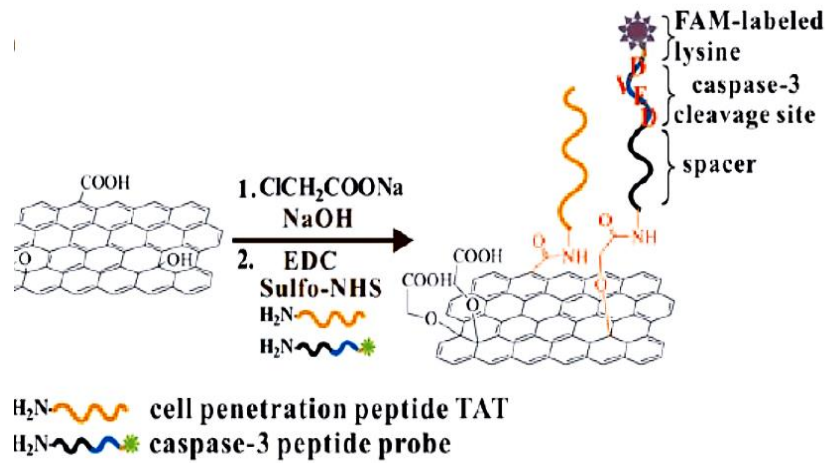


Figure 4. Peptide immobilization method on GO surface

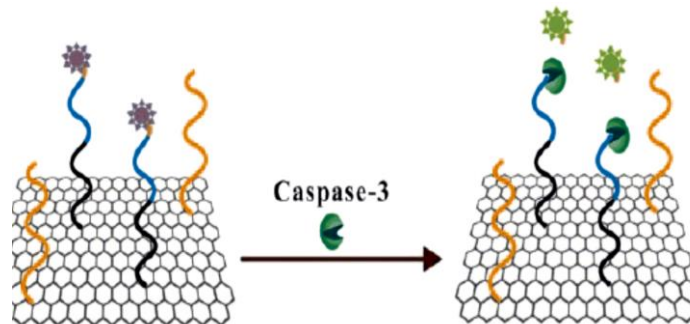


Figure 5. Identification of caspase 3 using graphene oxide-peptide Nano hybrid

The development of new biosensors with high sensitivity, selectivity and speed is of particular importance in identifying pathogens, medical diagnoses, safety screening and preventing environmental pollution. GO has a high potential for use in biosensors due to its unique properties such as easy surface change, high strength, good dispersibility in water and photoluminescence. In recent years, Zhang and colleagues reported a GO-

based biosensor for detecting rotavirus as a pathogen in which GO was deposited on the amine modified glass surface and the rotavirus antibody was fixed on the GO surface through the amide formation reaction with the help of carbodiimide. Then, the second rotavirus antibody is attached to the gold nanoparticle by means of a DNA molecule as an intermediary [12].

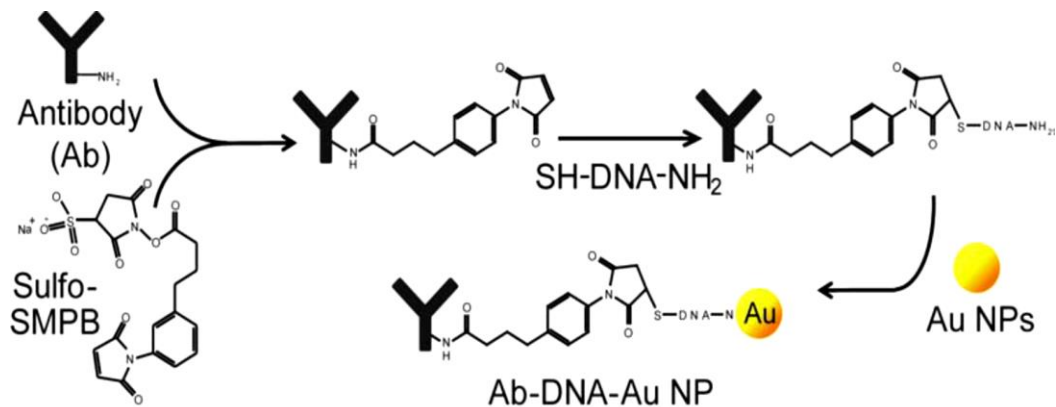
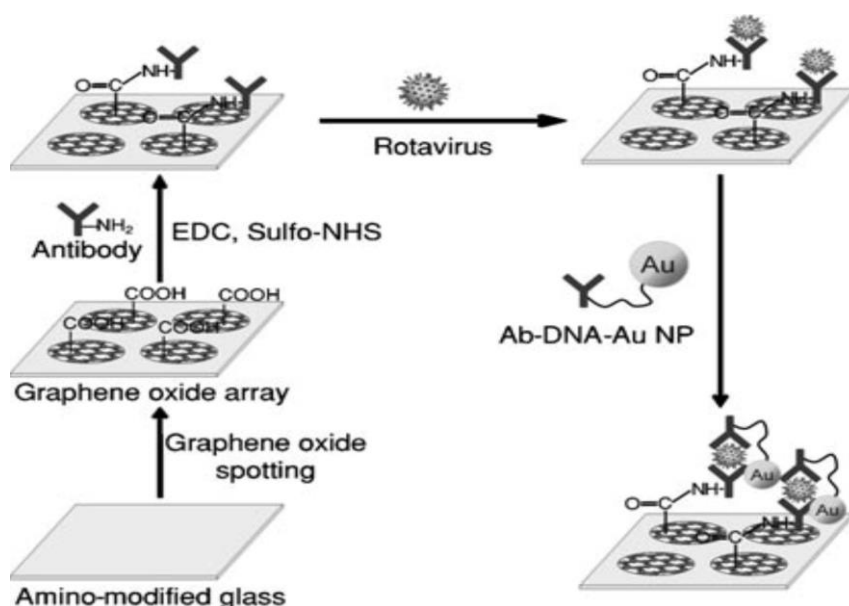


Figure 6. How to form the Ab-DNA-AuNP complex?

When the rotavirus cell in the target sample is attached to the antibody on the surface of GO by specific antibody-antigen interaction, the binding of the target cell has been confirmed by observing the decrease in GO fluorescence through FERT between

GO and the gold nanoparticle attached to the second antibody. In this way, it has become possible to identify the pathogen by means of a biosensor [13].



**Figure 7.** GO-based biosensor.

Zhu and co-workers recently reported GO-based fluorescent dye-containing probes to detect specific DNA sequences [14-16]. They identified three nucleotide sequences related to AIDS (HIV), smallpox (VV) and Ebola (EV) viruses using Alex Fluor 488, ROX and Cy5 organic dyes, respectively [17].

### Conclusion

In the first step, single-stranded DNA probes with organic dyes were adsorbed on the GO surface, and in the next step, by adding complementary DNA to each of the probes (target DNAs (T1, T2, T3), the probes were hybridized with the target DNAs and separated from the GO surface. The first step was associated with a sharp decrease in the fluorescence intensity and the second step was associated with an increase in the fluorescence intensity of the organic dyes. Under the optimal conditions, the relationship between the fluorescence intensity Organic dyes Alex Fluor 488, ROX and Cy5 and the concentration of target DNAs in Tris-HCl buffer have been checked. Using GO, Lu and his colleagues identified DNA and protein biomolecules with high sensitivity and selectivity. For this purpose, they used a DNA probe related to the AIDS virus and a human thrombin aptamer, each of which was labeled with the fluorescent dye FAM.

FAM-labeled single-stranded DNA probe (P1) was attached to GO sheets through non-covalent interactions, which was accompanied by a decrease in FAM fluorescence intensity. Then, with the

addition of the target DNA (HIV1), P1 is hybridized with it, and the resulting double-stranded DNA is separated from the GO surface, which increases the intensity of FAM fluorescence.

### Disclosure Statement

No potential conflict of interest reported by the authors.

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### Authors' Contributions

All authors contributed to data analysis, drafting, and revising of the paper and agreed to be responsible for all the aspects of this work.

### References

- [1] Samimi, A. (2024), [Risk Management in EPC Projects](#), Eurasian Journal of Chemical, Medicinal and Petroleum Research 3 (5), 185-195
- [2] Sadr, M. B. (2025). [Analysis of Spatial Criteria of Industries in the Village Based on Environmental Standards](#). Journal of Chemical Engineering and Energy Materials, 1(1), 1-8. doi: 10.22034/jceem.2025.220371
- [3] Samimi, A. (2021), [The Need for Risk Assessment in Occupational Health](#), Journal of Engineering in Industrial Research 2 (2), 71-76

- [4] Hwang, B. G., Zhao, X., & Toh, L. P. (2014). [Risk management in small construction projects in Singapore: Status, barriers and impact](#). *International Journal of Project Management*, 32(1), 116-124.
- [5] Samimi, A. Bozorgian, A. Samimi, M. (2022), [An Analysis of Risk Management in Financial Markets and Its Effects](#), *Journal of Engineering in Industrial Research* 3 (1), 1-7, 2022
- [6] Navaei, O. [Personalized Medicine: Tailoring Treatment Plans Based on Genetic Profile](#), *Eurasian Journal of Chemical, Medicinal and Petroleum Research*, 2025, 4 (2), 129-151
- [8] Samimi, A. (2020), [Investigation the Impact of Risk Management and Audit Committee on Industrial Companies](#), *Journal of Exploratory Studies in Law and Management* 7 (3), 132-137
- [9] Liu, H. C., Liu, L., & Liu, N. (2013). [Risk evaluation approaches in failure mode and effects analysis: A literature review](#). *Expert Systems with Applications*, 40(2), 828-838.
- [10] Imanzadeh, M. [Development of Solid State Electrolytes for Next Generation Lithium-Ion Batteries](#), *Eurasian Journal of Chemical, Medicinal and Petroleum Research*, 2025, 4 (1), 32-47
- [11] Zbuzant, M. (2025). [The goals of creating rural industries with the view of environmental protection](#). *Journal of Chemical Engineering and Energy Materials*, 1(1), 9-14. doi: 10.22034/jceem.2025.220372
- [12] Samimi, A. (2021), [The Need for Risk Assessment in Occupational Health](#), *Journal of Engineering in Industrial Research* 2 (2), 71-76
- [13] Singh, R., & Verma, A. (2025). [Risk management strategies in large-scale infrastructure projects](#). *IOSR Journal of Business and Management*, 26(6), 38-43.
- [14] Ahmadpour, A. and Jalali, M. (2023). [Introduction of Consumable Primers in Consumable Tires of Petrochemical Complexes in Hard Rubber Types](#). *Eurasian Journal of Chemical, Medicinal and Petroleum Research*, 2(5), 45-56.
- [15] Gandomi, MJ. [Use of New Technologies for Enhanced CO2 Reduction Reactions](#), *Eurasian Journal of Chemical, Medicinal and Petroleum Research*, 2025, 4 (1), 15-31
- [16] Sabzehali, S. [Nanomaterials in Drug Delivery Systems: Challenges and Perspectives](#), *Eurasian Journal of Chemical, Medicinal and Petroleum Research*, 2025, 4 (1), 48-62
- [17] Kiamansouri, M. [Integration of Renewable Energy Sources in Oil and Gas Operations a Sustainable Future](#), *Eurasian Journal of Chemical, Medicinal and Petroleum Research*, 2025, 4 (1), 63-87