

Electrochemical production of Graphene Oxide and its application as a novel Hydrogen Peroxide sensor

Hilal Demir Kivrak*, Nahit Aktas, Aykut Caglar

Van Yuzuncu Yil University, Faculty of Engineering, Chemical Engineering Department, 65000, Van, Turkey

Received 23 December 2018, revised 13 February 2019, accepted 16 February 2019, available online 26 February 2019

Abstract

Herein, graphene oxide is produced by electrochemical oxidation method from graphite rod to examine its hydrogen peroxide sensing ability. The electrochemically produced graphene oxide is characterized by SEM. A few layers of Graphene Oxide (GO) sheets and corrugations in graphene sheets appeared intensely crumpled and folded into a typical wrinkled structure after electrochemical oxidation. Electrochemical measurements are carried out cyclic voltammetry (CV) and chronoamperometry (CA) on graphene oxide and graphite. As a result, graphene oxide exhibits the highest performance toward electrochemical oxidation of H_2O_2 in 0.1 M phosphate buffered solution (PBS). In addition, CA is employed for the determination of H_2O_2 at the applied potential of 0.0 V (vs. Ag/AgCl). The electrochemical sensor exhibits fast and selective responses to H_2O_2 concentration.

Keywords: Electrochemical; Graphene Oxide; Graphite; Hydrogen Peroxide; Nonenzymatic Sensor.

How to cite this article

Kivrak HD, Aktas N, Caglar A. Electrochemical production of Graphene Oxide and its application as a novel Hydrogen Peroxide sensor. *Int. J. Nano Dimens.*, 2019; 10 (3): 252-259.

INTRODUCTION

Graphene is an allotrope form of carbon consisting of a single layer carbon in hexagonal crystal lattice, separated from 3D structured graphite. Graphene is known as the first two-dimensional structure and thinnest material at one atom thick and incredibly strong about 200 times stronger than steel with its superior performance and potential applications [1-7]. Graphene production techniques have been known as mechanical cleavage, chemical peeling, epitaxial growth, Hummers method, sublimation of 4H-SiC, chemical vapor deposition (CVD), and electrochemical reduction [8-11]. Among these methods, electrochemical reduction is a cheap, short-time, and simple method [12].

Hydrogen peroxide (H_2O_2) is a typical product of oxidase based on enzymatic reactions and a substrate for peroxidases. Furthermore, H_2O_2 is a widespread and environmentally friendly oxidant for organic synthesis. H_2O_2 emits only water as a

byproduct and shows high atomic yield. As a result, it is widely used in food production, chemical synthesis, fuel cells, and pharmaceutical analysis due to its strong oxidizing properties. Therefore, the precise determination of H_2O_2 is an important focus [13-18]. Different analytical techniques and methods based on titrimetry, spectrophotometry, chromatography, chemiluminescence, and fluorescence have been developed for the determination and quantification of H_2O_2 [16, 19-21]. Among these methods, the electrochemical method has been focused on more and more attention on the account of its great advantages such as high sensitivity and selectivity, rapid response, and low cost [22-25].

Recently, graphene has been offered great potential in electrochemical sensor applications due to its exceptional physicochemical properties, including large surface area, higher electron conductivity, and better biocompatibility [26]. Furthermore, graphene is a promising carbon material, widely used for the preparation of hybrid

* Corresponding Author Email: hilalkivrak@gmail.com
hilalkivrak@yyu.edu.tr

nanomaterials owing to its distinct electronic, mechanical, and chemical properties [25, 27-31]. For instance, N'Diaye *et al.* [32] reported that Rh nanoparticles on the graphene support revealed great sensitivity towards H_2O_2 . Similarly, Asif *et al.* [33] reported that graphene oxide supported MgO- Al_2O_3 nanocomposite was a promising material, prepared by low cost and low temperature facile method for the electrochemical determination of H_2O_2 . Zhao *et al.* [34] investigated that graphene oxide (GO) AuNC nanocomposites were prepared layer-by-layer assembly method and this material had good sensitivity towards to H_2O_2 .

At present, GO was prepared via electrochemical method from graphite rods. These rods were characterized by surface analytical techniques such as SEM measurements. To investigate their H_2O_2 sensor activities, cyclic voltammetry (CV) and chronoamperometry (CA) techniques were employed.

EXPERIMENTAL

Materials and Equipments

Graphite rods purchased from Auto Pencil company (2B, diameter= 2 mm). H_2SO_4 was supplied from Sigma-Aldrich. Potentiostat, Ag/AgCl reference electrode, and Pt wire electrodes were purchased from CH Instruments. Deionized water was distilled by water purification system (Milli-Q Water Purification System). All glassware were washed with acetone and copiously rinsed with distilled water.

Electrochemical production of Graphene oxide

Graphite rods were used in order to produce GO rods by anodization technique applied via cyclic voltammetry (CV). Graphite rods were rinsed with water and dried at room temperature. Anodization measurements on the graphite rod working electrode were carried out in a conventional three electrode glass cell under the control of CHI 660 E potentiostat. On the other hand, Pt wire and Ag/AgCl (3 M KCl) electrodes were employed as counter electrode and reference electrode, respectively. 1.0 M H_2SO_4 solution was used as supporting electrolyte. On the other hand, prior

to anodization, Ar gas was bubbled throughout the electrochemical cell. Following this, electrochemical anodization of graphite rods were performed employing the same repetitive cyclic potential sweeping in 3-electrode configuration under the same conditions for longer period of time. Electrochemical preparation conditions of the graphite rods were presented in Table 1. These materials were characterized by Scanning electron microscopy (SEM). SEM measurements were carried out using a FEI QUANTA 250 FEG scanning electron microscope.

Electrochemical H_2O_2 oxidation measurements

Electrochemical measurements were performed on graphite and Graphene Oxide (GO) derived electrochemically. Hydrogen peroxide (H_2O_2) electrooxidation measurements were performed via cyclic voltammetry (CV) and chronoamperometry (CA). Electrochemical experiments were performed using a CHI 660E potentiostat in a conventional three electrode glass cell. The working electrode was graphite and GO rod. Pt wire and Ag/AgCl (3 M KCl) electrodes were employed as counter and reference electrodes, respectively. First of all, to compare the H_2O_2 electrooxidation activities of the graphite and GO electrodes, cyclic voltammograms were taken in 0.1 M phosphate buffer solution (PBS) with 10 mM H_2O_2 at -1-1 V with a scan rate of 50 mV s^{-1} . Following this, further CV measurements were performed on GO electrode at varying H_2O_2 concentrations. Amperometric measurements were executed in a 0.1 M PBS under stirred condition. Following this, response current was related with the change value between the steady-state current and background current.

The interference experiments were also carried out in 0.1 M phosphate buffer solution by adding 0.5 mM H_2O_2 , 0.5 mM ascorbic acid, 0.5 mM uric acid, and 0.5 mM H_2O_2 , respectively.

RESULTS AND DISCUSSION

Characterization

Scanning Electron Microscopy (SEM) images of graphite and Graphene Oxide (GO) were

Table 1. Electrochemical preparation conditions of the graphite rods.

Catalyst	Scan Rate	H_2SO_4 Solution	Precondition (s)	Potential range (V)	Measurement
GO rod	0.1 V/s	1.0 M	3600	-0.85:1.2	C V

given in Fig. 1a-b and Fig. 2a-b, respectively. GO sheets are folded into a wrinkled structure after electrochemical oxidation (see Fig. 2a-b). This wrinkled structure could provide enhanced mechanical properties, reduced surface energy, and increased surface roughness and area.

Electrochemical measurements of graphite and graphene oxide electrodes

The electrocatalytic reduction of hydrogen peroxide (H_2O_2) was studied on graphite and graphene oxide (GO) electrodes. The cyclic voltammetric responses for the reduction of 5 mM H_2O_2 at graphite and GO electrodes in N_2 -saturated

0.1 M phosphate buffered solution (PBS, pH=7.5) at scan rate of 50 mV s^{-1} were displayed in Fig. 3. The current density for H_2O_2 oxidation on GO was 2.5 times higher than the one for graphite. The improved electrochemical activity of GO may also result from electronic state change of graphite after electrochemical oxidation [16, 33, 35, 36].

As a result, GO exhibited higher H_2O_2 oxidation and reduction current than graphite. Further experimental studies were performed to examine the effect of H_2O_2 concentration on GO rod electrode for H_2O_2 oxidation and reduction. As shown in Fig. 4 (a,b), the oxidation and reduction currents gradually increases with rising the H_2O_2

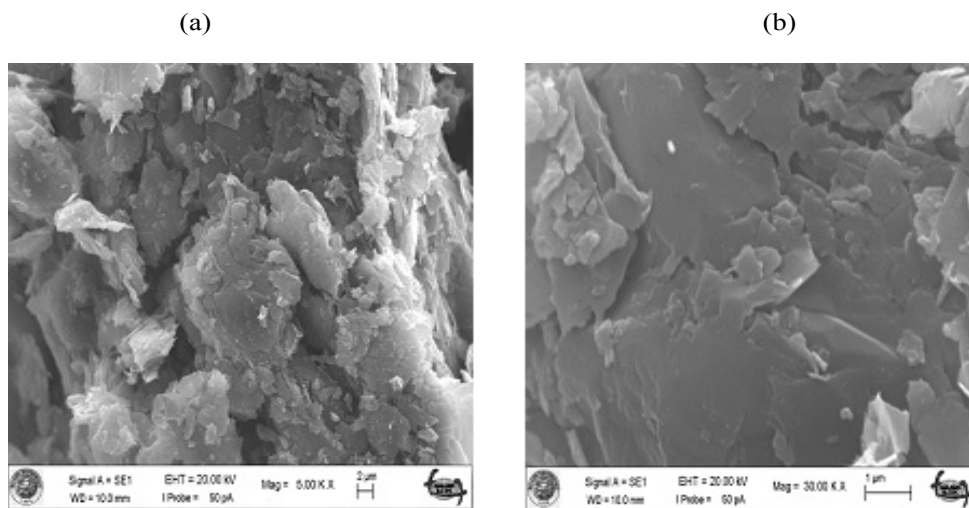


Fig. 1. SEM images a) low magnification b) high magnification of graphite.

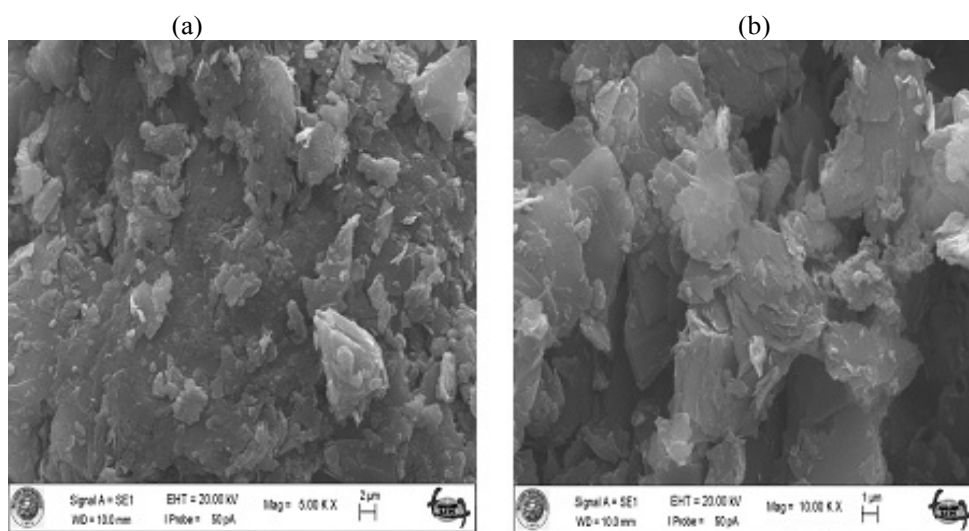


Fig. 2. SEM images a) low magnification b) high magnification of GO.

concentration (0.0-100 mM).

Amperometric measurements were performed to obtain an amperometric response of GO by the successive additions of H_2O_2 at varying potentials (Fig. 5). One could note that the best response was obtained at 0.0 V potential. The LOD values were

calculated the methods given in the literature [37]. As seen Fig. 5b, the sensor has a linear response range of 0.5 mM to 25 mM with a sensitivity of $11 \mu A m M^{-1} c m^{-2}$ ($R^2=0.99$). Moreover, the limit of detection (LOD) was 0.0975 mM. As a result, the GO could be used for the preparation of an

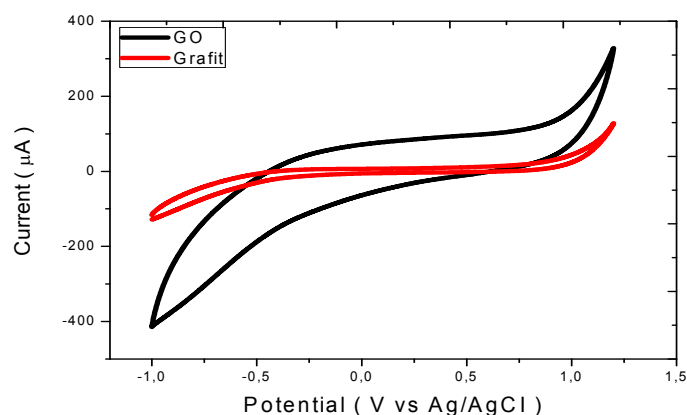


Fig. 3. CVs for the GO and Grafit in N_2 -saturated 0.1 M PBS at varying 5 mM H_2O_2 concentration scan rate: 50 mV s^{-1} .

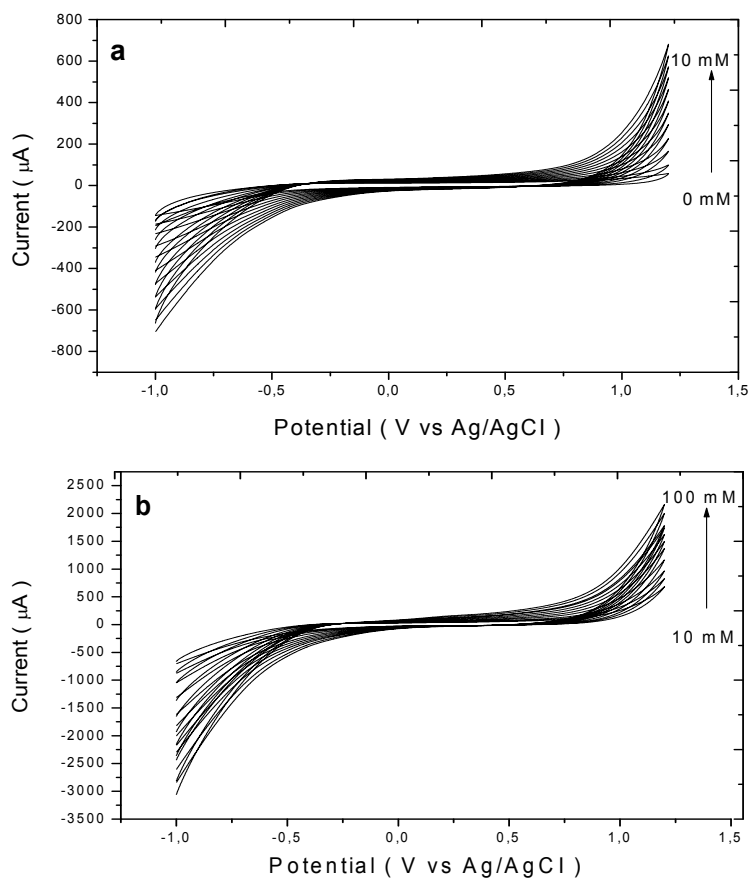


Fig.4. CVs for the GO in N_2 -saturated 0.1 M PBS at varying (a) 0-10 mM (b) 10-100 mM H_2O_2 concentrations scan rate: 50 mV s^{-1} .

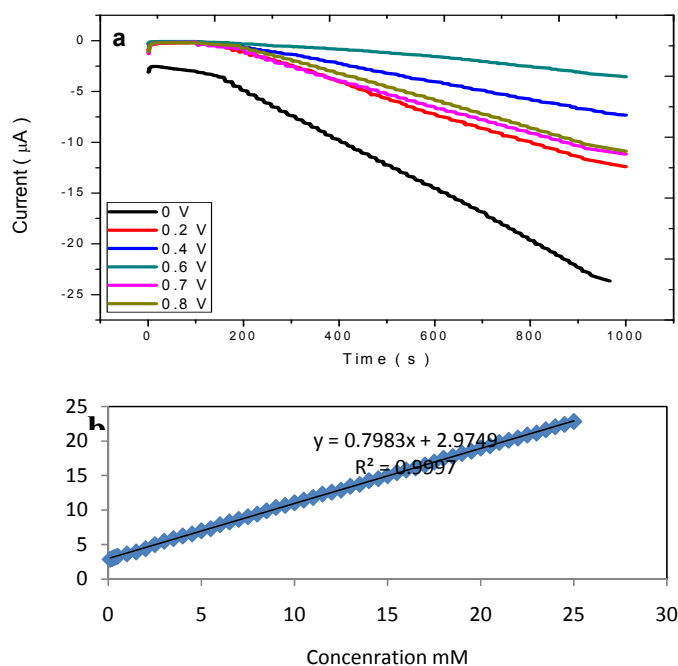


Fig. 5. (a) Amperometric response of GO to successive addition of H₂O₂ at varying potentials, (b) the calibration curve for H₂O₂ detection obtained from the amperometric response taken at 0.0 V.

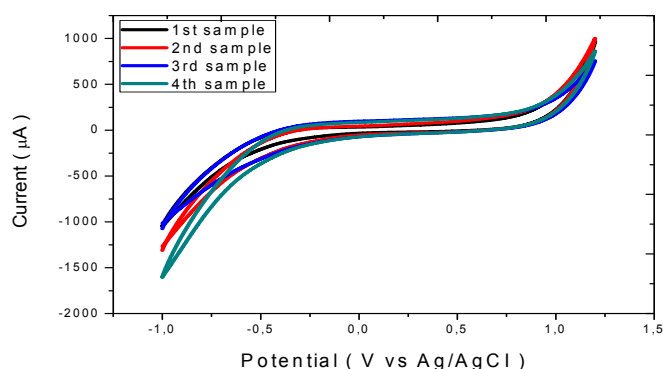


Fig. 6. The responses of four-parallel GO electrodes toward 20 mM H₂O₂.

Table 2. Comparison of different H₂O₂ sensors.

Catalyst	Applied Potential (V)	Linear range (mM)	Sensitivity	Detection Limit (µM)	Reference
PdCo/CNF-CPE	-0.15 (Ag/AgCl)	0.0002–23.5	6.64 (µA mM ⁻¹)	100	[36]
Pd-Co-CNTs/GCE	0.6 (Ag/AgCl)	0.01-2.4	75.4 (µA mM ⁻¹ cm ⁻²)	1000	[37]
p-SiNWs depositing 30s	-0.45 (SCE)	0.2-70	8.96 (µA mM ⁻¹ cm ⁻²)	200	[38]
GO rod	0.0 (Ag/AgCl)	0.5–25	11 (µA mM ⁻¹ cm ⁻²)	97.5	This work

amperometric H₂O₂ sensor with prompt response, high sensitivity, and wide linear range. Table 2 shows the comparison of linear range, detection limit, applied potential, and sensitivity of GO rod with other hydrogen peroxide sensors reported in literature. As seen Table 2, the analytical

performances of GO rod is nearly equivalent the other enzyme or non enzymatic H₂O₂ sensors in one or more categories [38-39]. Furthermore, GO rod exhibited good sensitivity in the literature studies compared with the support material and metal studies [16, 20, 24, 28, 32, 33, 35, 36, 41-47].

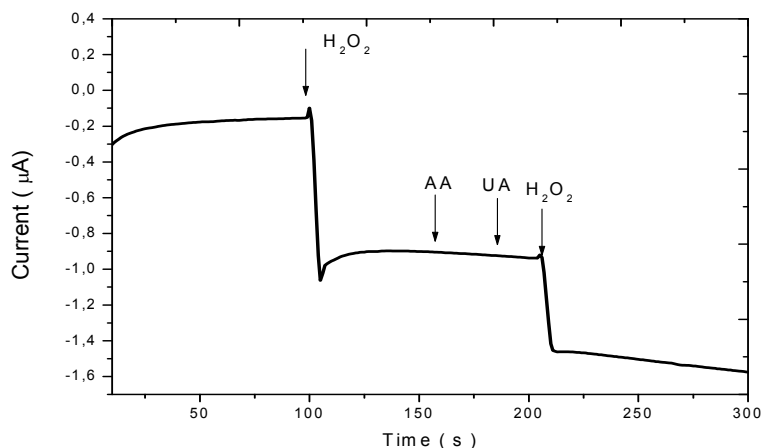


Fig. 7. Amperometric response of graphene oxide to successive addition of 0.5 mM H_2O_2 , AA, UA, H_2O_2 at 0.0 V.

Sample repeatability is an important parameter for the determination of H_2O_2 sensor sensitivity. In the present study, four samples were prepared and measured at the same conditions by CV. Results were given in Fig. 6. The repeatability of graphite oxide was performed using 20 mM H_2O_2 (Fig.6). Sample repeatability test for H_2O_2 detection for four successive runs on the same solution gave a RSD of 5 %.

The selectivity of the proposed H_2O_2 sensor was investigated in the existence of some various interferences such as ascorbic acid (AA) and uric acid (UA). Interference of these compounds to H_2O_2 sensor was examined by comparing the amperometric responses at 0.0 V. These responses were measured by successive additions of 0.5 mM H_2O_2 , AA, UA, and H_2O_2 . As shown in Fig. 7, the interferences give negligible signal changes [16, 35, 49-51].

CONCLUSIONS

Herein, graphite was electrochemically oxidized and as a result graphene oxide (GO) was obtained. GO and graphite was characterized by Scanning Electron Microscopy (SEM). GO sheets and corrugations in graphene sheets appeared intensely crumpled and folded into a typical wrinkled structure after electrochemical oxidation. Furthermore, electrochemical measurements were performed to investigate the electrochemical sensing ability of GO. Optimized sensor revealed fine analytical parameters such as linear range from 0.5 mM to 25 mM, lower detection limit (0.0975 mM), and $11 \mu\text{A mM}^{-1} \text{cm}^{-2}$ sensitivity. Furthermore, GO rod exhibited good sensitivity in

the literature studies compared with the support material and metal studies. In conclusion, the study of the preparation, characterization, and employment of these catalysts as sensor led to the following conclusions and insights:

- GO could be easily prepared from the electrochemical oxidation of graphite. GO is efficient material for H_2O_2 electrooxidation activity compared to graphite.
- The morphology of GO and graphite were characterized by SEM. These measurements revealed that GO was prepared, successfully. In addition, the H_2O_2 sensing ability of GO is better than graphite due to corrugations in graphene sheets.
- The sensor exhibits a comprehensive performance, including good sensitivity, low detection limit, and wide linearity toward the detection of H_2O_2 .

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

REFERENCES

1. Bollella P., Fusco G., Tortolini C., Sanzò G., Favero G., Gorton L., Antiochia R., (2017), Beyond graphene: Electrochemical sensors and biosensors for biomarkers detection. *Biosens. Bioelect.* 89: 152-166.
2. Geng D., Bo X., Guo L., (2017), Ni-doped molybdenum disulfide nanoparticles anchored on reduced graphene oxide as novel electroactive material for a non-enzymatic glucose sensor. *Sens. Actuat. B: Chem.* 244: 131-141.
3. Wang C.-H., Yang C.-H., Chang J.-K., (2017), High-selectivity electrochemical non-enzymatic sensors based on graphene/Pd nanocomposites functionalized with

- designated ionic liquids. *Biosens. Bioelect.* 89: 483-488.
4. Tajabadi M. T., Sookhakian M., Zalnezhad E., Yoon G. H., Hamouda A. M. S., Azarang M., Basirun, W. J., Alias Y., (2016), Electrodeposition of flower-like platinum on electrophoretically grown nitrogen-doped graphene as a highly sensitive electrochemical non-enzymatic biosensor for hydrogen peroxide detection. *Appl. Surf. Sci.* 386: 418-426.
 5. Tahmasebi S., Moradi O., Yari, M., (2016), Kinetics adsorption of Amoxicillin from aqueous solution by Graphen Oxide-Gold nanoparticles (GO-AuNPs) nanocomposite as novel adsorbent. *Int. J. Nano Dimens.* 7: 144-149.
 6. Allahbakhsh A., Sharif F., Mazinani S., Kalaei M. R., (2014), Synthesis and characterization of Graphene Oxide in suspension and powder forms by chemical exfoliation method. *Int. J. Nano Dimens.* 5: 11-20.
 7. Syarif N., (2013), First principles studies on band structures and density of states of graphite surface oxides. *Int. J. Nano Dimens.* 4: 57-62.
 8. Tan Y. Y., Jayawardena K. D. G. I., Adikaari A. A. D. T., Tan L. W., Anguita J. V., Henley S. J., Stolojan V., Carey J. D., Silva S. R. P., (2012), Photo-thermal chemical vapor deposition growth of graphene. *Carbon.* 50: 668-673.
 9. Yao Y., Wong C.-p., (2012), Monolayer graphene growth using additional etching process in atmospheric pressure chemical vapor deposition. *Carbon.* 50: 5203-5209.
 10. Liu R., Chi Y., Fang L., Tang Z., Yi, X., (2014), Synthesis of carbon nanowall by plasma-enhanced chemical vapor deposition method. *J. Nanosci. Nanotechnol.* 14: 1647-1657.
 11. Seo J., Lee J., Jang A. R., Choi Y., Kim U., Shin H. S., Park H., (2017), Study of cooling rate on the growth of graphene via chemical vapor deposition. *Chem. Mater.* 29: 4202-4208.
 12. Chen K., Chen L., Chen Y., Bai H., Li L., (2012), Three-dimensional porous graphene-based composite materials: electrochemical synthesis and application. *J. Mater. Chem.* 22: 20968-20976.
 13. Kazici Hilal C., Salman F., Kivrak Hilal D., (2017), Synthesis of Pd-Ni/C bimetallic materials and their application in non-enzymatic hydrogen peroxide detection. In *Materials Science-Poland*, p 660.
 14. Lacina K., Kubesa O., Vanýsek P., Horáčková V., Moravec Z., Skládal P., (2017), Selective electrocatalysis of reduced graphene oxide towards hydrogen peroxide aiming oxidases-based biosensing: Caution while interpreting. *Electrochim. Acta.* 223: 1-7.
 15. Thakur S., Kshetri T., Kim N. H., Lee J. H., (2017), Sunlight-driven sustainable production of hydrogen peroxide using a CdS-graphene hybrid photocatalyst. *J. Catal.* 345: 78-86.
 16. Çelik Kazıcı H., Caglar A., Aydogmus T., Aktas N., Kivrak H., (2018), Microstructured Prealloyed Titanium-Nickel Powder As a Novel Nonenzymatic Hydrogen Peroxide Sensor. *J. Colloid and Interf. Sci.* 530: 353-360.
 17. Thanh T. D., Balamurugan J., Lee S. H., Kim N. H., Lee J. H., (2016), Novel porous gold-palladium nanoalloy network-supported graphene as an advanced catalyst for non-enzymatic hydrogen peroxide sensing. *Biosens. Bioelectron.* 85: 669-678.
 18. Kazici H. C., Salman F., Caglar A., Kivrak H., Aktas N., (2018), Synthesis, characterization, and voltammetric hydrogen peroxide sensing on novel monometallic (Ag, Co/MWCNT) and bimetallic (AgCo/MWCNT) alloy nanoparticles. *Fulleren. Nanotubes Carbon Nanostruc.* 26: 145-151.
 19. Yang X., Ouyang Y., Wu F., Hu Y., Ji Y., Wu Z., (2017), Size controllable preparation of gold nanoparticles loading on graphene sheets@cerium oxide nanocomposites modified gold electrode for nonenzymatic hydrogen peroxide detection. *Sens. Actuat. B: Chem.* 238: 40-47.
 20. Sookhakian M., Zalnezhad E., Alias Y., (2017), Layer-by-layer electrodeposited nanowall-like palladium-reduced graphene oxide film as a highly-sensitive electrochemical non-enzymatic sensor. *Sens. Actuat. B: Chem.* 241: 1-7.
 21. Sahin O., Kivrak H., Kivrak A., Kazıcı H. Ç., Alal O., Atbas D., (2017), Facile and rapid synthesis of microwave assisted Pd nanoparticles as non-enzymatic hydrogen peroxide sensor, *Int. J. Electrochem. Sci.* 12: 762-769.
 22. Wu Z.-L., Li C.-K., Yu J.-G., Chen X.-Q., (2017), MnO₂/reduced graphene oxide nanoribbons: Facile hydrothermal preparation and their application in amperometric detection of hydrogen peroxide. *Sens. Actuat. B: Chem.* 239: 544-552.
 23. Qiu W., Zhu Q., Gao F., Gao F., Huang J., Pan Y., Wang Q., (2017), Graphene oxide directed in-situ synthesis of Prussian blue for non-enzymatic sensing of hydrogen peroxide released from macrophages. *Mater. Sci. Eng. C.* 72: 692-700.
 24. Zhang R., Chen W., (2017), Recent advances in graphene-based nanomaterials for fabricating electrochemical hydrogen peroxide sensors. *Biosens. Bioelectron.* 89: 249-268.
 25. Liu Y., Liu X., Guo Z., Hu Z., Xue Z., Lu X., (2017), Horseradish peroxidase supported on porous graphene as a novel sensing platform for detection of hydrogen peroxide in living cells sensitively. *Biosens. Bioelectron.* 87: 101-107.
 26. Beitollahi H., Safaei M., Tajik S., (2018), Application of Graphene and Graphene Oxide for modification of electrochemical sensors and biosensors: A review. *Int. J. Nano Dimens.* 10:125-140.
 27. Yusoff N., Rameshkumar P., Mehmood M. S., Pandikumar A., Lee H. W., Huang N. M., (2017), Ternary nanohybrid of reduced graphene oxide-nafion@silver nanoparticles for boosting the sensor performance in non-enzymatic amperometric detection of hydrogen peroxide. *Biosens. Bioelectron.* 87: 1020-1028.
 28. Xue W., Bo X., Zhou M., Guo L., (2016), Enzymeless electrochemical detection of hydrogen peroxide at Pd nanoparticles/porous graphene. *J. Electroanal. Chem.* 781: 204-211.
 29. Zhao C., Zhang H., Zheng J., (2017), A non-enzymatic electrochemical hydrogen peroxide sensor based on Ag decorated boehmite nanotubes/reduced graphene oxide nanocomposites. *J. Electroanal. Chem.* 784: 55-61.
 30. Zahraei F., Rahimi K., Yazdani A., (2015), Preparation and characterization of Graphene/Nickel Oxide nanorods composite. *Int. J. Nano Dimens.* 6: 371-376.
 31. Elsagh A., (2014), Enhanced electrical conductivity properties of Graphene Oxide nanocomposites functionalized with Polyvinyl Alcohol. *Int. J. Nano Dimens.* 5: 447-451.
 32. N'Diaye J., Poorahong S., Hmam O., Izquierdo R., Sijaj M., (2017), Facile synthesis rhodium nanoparticles decorated single layer graphene as an enhancement hydrogen peroxide sensor. *J. Electroanal. Chem.* 789: 85-91.
 33. Asif S. A. B., Khan S. B., Asiri A. M., (2017), Assessment of graphene oxide/MgAl oxide nanocomposite as a non-enzymatic sensor for electrochemical quantification of

- hydrogen peroxide. *J. Taiwan Inst. Chem. Eng.* 74: 255-262.
34. Zhao S., Zhang J., Li Z., Zhang P., Li Y., Liu G., Wang Y., Yue Z., (2017), Photoelectrochemical determination of hydrogen peroxide using a gold electrode modified with fluorescent gold nanoclusters and graphene oxide. *Microchim. Acta.* 184: 677-686.
 35. Kivrak H., Alal O., Atbas D., (2015), Efficient and rapid microwave-assisted route to synthesize Pt-MnOx hydrogen peroxide sensor. *Electrochim. Acta.* 176: 497-503.
 36. Liu D., Guo Q., Zhang X., Hou H., You T., (2015), PdCo alloy nanoparticle-embedded carbon nanofiber for ultrasensitive nonenzymatic detection of hydrogen peroxide and nitrite. *J. Colloid and Interf. Sci.* 450: 168-173.
 37. Huang B., Wang Y., Lu Z., Du H., Ye J., (2017), One pot synthesis of palladium-cobalt nanoparticles over carbon nanotubes as a sensitive non-enzymatic sensor for glucose and hydrogen peroxide detection. *Sensors and Actuators B: Chem.* 252: 1016-1025.
 38. Yin J., Qi X., Yang L., Hao G., Li J., Zhong J., (2011), A hydrogen peroxide electrochemical sensor based on silver nanoparticles decorated silicon nanowire arrays. *Electrochim. Acta.* 56: 3884-3889.
 39. Huang B., Wang Y., Lu Z. W., Du H. J., Ye J. S., (2017), One pot synthesis of palladium-cobalt nanoparticles over carbon nanotubes as a sensitive non-enzymatic sensor for glucose and hydrogen peroxide detection. *Sens. Actuat. B-Chem.* 252: 1016-1025.
 40. Zapp E., Nascimento V., Dambrowski D., Braga A. L., Vieira I. C., (2013), Bio-inspired sensor based on glutathione peroxidase mimetic for hydrogen peroxide detection. *Sens. Actuat. B-Chem.* 176: 782-788.
 41. Xu B., Ye M.-L., Yu Y.-X., Zhang W.-D., (2010), A highly sensitive hydrogen peroxide amperometric sensor based on MnO₂-modified vertically aligned multiwalled carbon nanotubes. *Analyt. Chim. Acta.* 674: 20-26.
 42. Guzman C., Orozco G., Verde Y., Jimenez S., Godinez L. A., Juaristi E., Bustos E., (2009), Hydrogen peroxide sensor based on modified vitreous carbon with multiwall carbon nanotubes and composites of Pt nanoparticles-dopamine. *Electrochim. Acta.* 54: 1728-1732.
 43. Azizi S. N., Ghasemi S., Samadi-Maybodi A., Ranjbar-Azad M., (2015), A new modified electrode based on Ag-doped mesoporous SBA-16 nanoparticles as non-enzymatic sensor for hydrogen peroxide. *Sens. Actuat. B-Chem.* 216: 271-278.
 44. Meng L., Jin J., Yang G., Lu T., Zhang H., Cai C., (2009), Nonenzymatic electrochemical detection of glucose based on Palladium-single-walled carbon nanotube hybrid nanostructures. *Analyt. Chem.* 81: 7271-7280.
 45. Tavakkoli N., Nasrollahi S., (2013), Non-enzymatic glucose sensor based on palladium coated nanoporous gold film electrode. *Austral. J. Chem.* 66: 1097-1104.
 46. Ding L. H., Su B., (2015), A non-enzymatic hydrogen peroxide sensor based on platinum nanoparticle-polyaniline nanocomposites hosted in mesoporous silica film. *J. Electroanal. Chem.* 736: 83-87.
 47. Li H. X., Shen C. Y., Wu Q., Xia W. S., (2014), Performance improvement of hydrogen peroxide sensor via Cadmium doped Nickel Oxide modifying n-silicon electrode. In *Innov. Mater.: Eng. Appl.* (Bhatnagar, A. K., Ed.) pp 69-72.