A novel electrochemical sensor for determination of DNA damage biomarker (8-hydroxy-2'-deoxyguanosine) in urine using sonochemically derived graphene oxide sheets covered zinc oxide flower modified electrode

Mani Govindasamy, Sea-Fue Wang, Bowya Subramanian, R. Jothi Ramalingam, Hamad Al-lohedan, Anandraj Sathiyan

PII: S1350-4177(19)30371-2
DOI: https://doi.org/10.1016/j.ultsonch.2019.104622
Article Number: 104622
Reference: ULTSON 104622

To appear in: *Ultrasonics Sonochemistry*

Received Date: 9 March 2019
Revised Date: 30 May 2019
Accepted Date: 30 May 2019

Please cite this article as: M. Govindasamy, S-F. Wang, B. Subramanian, R. Jothi Ramalingam, H. Al-lohedan, A. Sathiyan, A novel electrochemical sensor for determination of DNA damage biomarker (8-hydroxy-2'-deoxyguanosine) in urine using sonochemically derived graphene oxide sheets covered zinc oxide flower modified electrode, *Ultrasonics Sonochemistry* (2019), doi: https://doi.org/10.1016/j.ultsonch.2019.104622

A novel electrochemical sensor for determination of DNA damage biomarker (8-hydroxy-2'-deoxyguanosine) in urine using sonochemically derived graphene oxide sheets covered zinc oxide flower modified electrode

Mani Govindasamy[a], Sea-Fue Wang[a,*], Bowya Subramanian[b,c], R. Jothi Ramalingam[d,*], Hamad Al-lohedan[d], Anandraj Sathiyan[e]

[a]Department of Materials and Mineral Resources Engineering, National Taipei University of Technology, No. 1, Sec. 3, Chung-Hsiao East Rd., Taipei 106, Taiwan.

[b]Department of Chemical Engineering and Biotechnology, National Taipei University of Technology, No.1, Section 3, Chung-Hsiao East Road, Taipei 106, Taiwan.

[c]Department of Information Technology, KSR College of Engineering, Tiruchengode, Tamil Nadu, India.

[d]Surfactant Research Chair, Chemistry Department, College of Science, King Saud University, P.O. Box-2455, Riyadh-11451, Kingdom of Saudi Arabia.

[e]Department of chemistry, Bishop Heber College, Trichy-620017, Tamil Nadu, India.

Corresponding authors: [*]S.-F. Wang, Email: sfwang@ntut.edu.tw and [*]R.-J. Ramalingam, Email: jrajabathar@ksu.edu.sa.

----------***----------

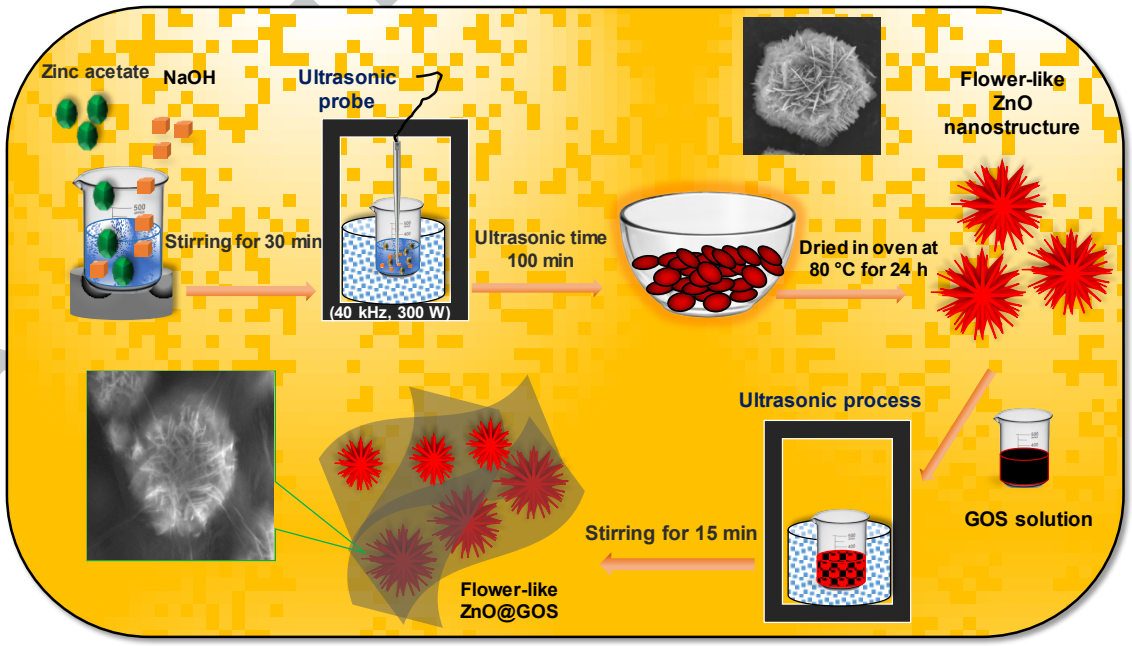
Abstract

To explore a novel and multi-layer based graphene oxide covered zinc oxide nanoflower (ZnO NFs@GOS) as a modified electrode materials by sonochemical technique (40 kHz, 300 W). Herein, novel nanocomposite is successfully characterized by various characterization analysis (FESEM, HRTEM, XRD, XPS and (EIS) electrochemical impedance spectroscopy) and employed as high sensitive modified electrode (ZnO NFs@GOS nanocomposite) for the electrochemical determination of biomarker. 8-hydroxy-2'-deoxyguanosine (8-HDG) is one of the important cancer and oxidative stress biomarker. The results demonstrated that the ZnO NFs@GOS modified SPCE reveal well-defined electro-oxidation peak at 0.36 V (vs. Ag/AgCl). The high sensitive properties of the optimized flower like modified electrode are because of the excellent synergistic effect of the ZnO flower and the graphene oxide nanosheets, as evidenced by a superior bio-sensing performance. The nanocomposite fabricated modified biosensor was facilitating the analysis of 8-HDG in the concentration ranges of 0.05 to 536.5 μM with a low detection limit is 8.67 nM. The ZnO NFs@GOS modified sensor can also employed for the determination of 8-HDG in human urine samples, promising its application towards the quantification of cancer biomarker in biological samples.

Keywords: Zinc oxide nanoflower; Sonochemical synthesis; DNA damage biomarker; Graphene oxide nanosheets; Urine real sample.

1. Introduction

The progress of the more effective electrocatalyst as a substitute for a semiconductor based transition metal oxides (TMOs) as an emerging electrode material of nano-research in the analytical world. Due to their excellent physicochemical properties [1-4], which is suitable for electrocatalysis and various energy applications such as metal-air batteries, fuel cells and sensor materials [5-9]. However, the use of TMOs and their nanocomposites in real-time applications are benefit by their low-cost and high electrocatalytic effect [10-13]. Furthermore, synthesis method also more benefit based on cost-effective and green effective method. Therefore, sonochemical and ultrasound assisted method has highly effective method for green and toxic free solvent technique [14-16]. The development of an environmental effective and earth-abundant electrode nanomaterial for outstanding sensing performance retains a great challenge. Zinc oxide (ZnO) based nanocomposites have been widely used as the electrode materials for the electrochemical applications [17].



Scheme 1. Sonochemical synthesis of ZnO NFs@GOS nanocomposite

In this study established a simple and eco-feiendly approach to fabricate the nanocomposite of ZnO NFs@GOS nanocatalyst through a sonochemical technique and employed as an effective electrode material for non-enzymatic bio-sensing applications. Furthermore, these studies reveals that the flower based ZnO NFs covered with GOS nanocatalyst enhance the electrocatalytic performance towards biomarker detection. Moreover, compare with other TMOs, the ZnO is low cost and easy to synthesize by ultrasound approach. Therefore, we have synthesized the ZnO NFs@GOS catalyst based nanomaterial via sonochemical process. However, ZnO NFs with carbonaceous-based nanomaterials that are exhibited the excellent electrochemical properties. Therefore, the presence of graphene oxide sheets (GOS) nanomaterials can improve the structure stability of the nanocomposite [18-22]. Because, GOS is good nanomatrix due to their unique properties including large surface area and electron mobility [23-29]. Furthermore, the graphene oxide is essential for improving the electrochemical surface area of nanocomposite and fabricating the nanomaterials as a modified electrode. As a result, the synthesized ZnO NFs was combine with GOS using the simple sonochemical approach at room temperature.

8-hydroxy-2'-deoxyguanosine (8-HDG) is an important cancer biomarker and it is endogenous-oxidative stress biomarker [30, 31]. Furthermore, 8-HDG is an important signal biomolecule for various biological and chemical processes in DNA (deoxyribonucleic acid) functions. Studies on the electroanalytical chemistry of 8-HDG is significant as it regulates DNA functions and play significant role in treatment of cancer diseases [32, 33]. An abnormal concentration level is an indication of DNA damages in the body [34, 35]. Therefore, monitoring the 8-HDG concentration is great importance and challenge to the

analytical researchers. Therefore, various detection methods including such as high performance liquid chromatography (HPLC), HPLC tandem mass spectrometry, solid phase extraction and DNA-based electrochemical analysis (DNA-EA) [36, 37]. Furthermore, the electrochemical methods were used for the sensing application due to the cost effective and simplicity of the method. Thus, we can apply the electrochemical method for the determination of 8-HDG in biological samples.

In the present work, the synthesized ZnO NFs@GOS nanocomposite was characterized and fabricated by a simple drop-casted method. Then, the fabricated and nanocomposite modified electrodes was applied to the determination of 8-HDG. Moreover, the sensitivity and practical feasibility of the modified electrodes were evaluated by cyclic voltammetry and amperometric techniques (**Scheme 1**).

2. Experimental section

2.1 Synthesis of ZnO NFs@GOS nanocomposite

All reagents and chemicals were collected from Sigma-Aldrich and used without any other purifications (chemicals and methods detail are given in supporting information file). Flower-like ZnO nanostructures were synthesized by a simple sonochemical method [38]. In a typical procedure, 20 mL of 0.1 M zinc acetate aqueous solution and 20 mL 1 M potassium hydroxide aqueous solution were added to 40 mL double distilled water. After vigorous magnetic stirring for 15 min, the resulting mixture containing beaker was then instantly kept in sonication bath (40 kHz, 300 W) at room temperature for ultrasonic time (100 min). The precipitates were centrifuged and washed with double distilled water and ethanol several times and finally product was dried in an oven at 80°C for 12 h. Then, the

ZnO NFs@GOS nanocomposite was prepared with graphene oxide. A typical preparation 10 mg of ZnO NFs was subsequently added to the pre-prepared mixture solution of GOS in 20 mL of deionized water and then ultrasonicated for 10 min (**Scheme 1**).

2.2. Fabrication of ZnO NFs@GOS modified electrode

The ZnO NFs@GOS nanomaterials dispersed solution (2 mg/mL; water) about eight µL was drop casted on the SPCE. Then, the ZnO NFs@GOS drop-casted electrode was dried at 55˚C. The same produce was applied to fabricate the control electrodes such as GOS and ZnO NFs. The electrocatalyst modified electrodes were applied for the electrochemical determination towards the 8-HDG **(Scheme 1).**

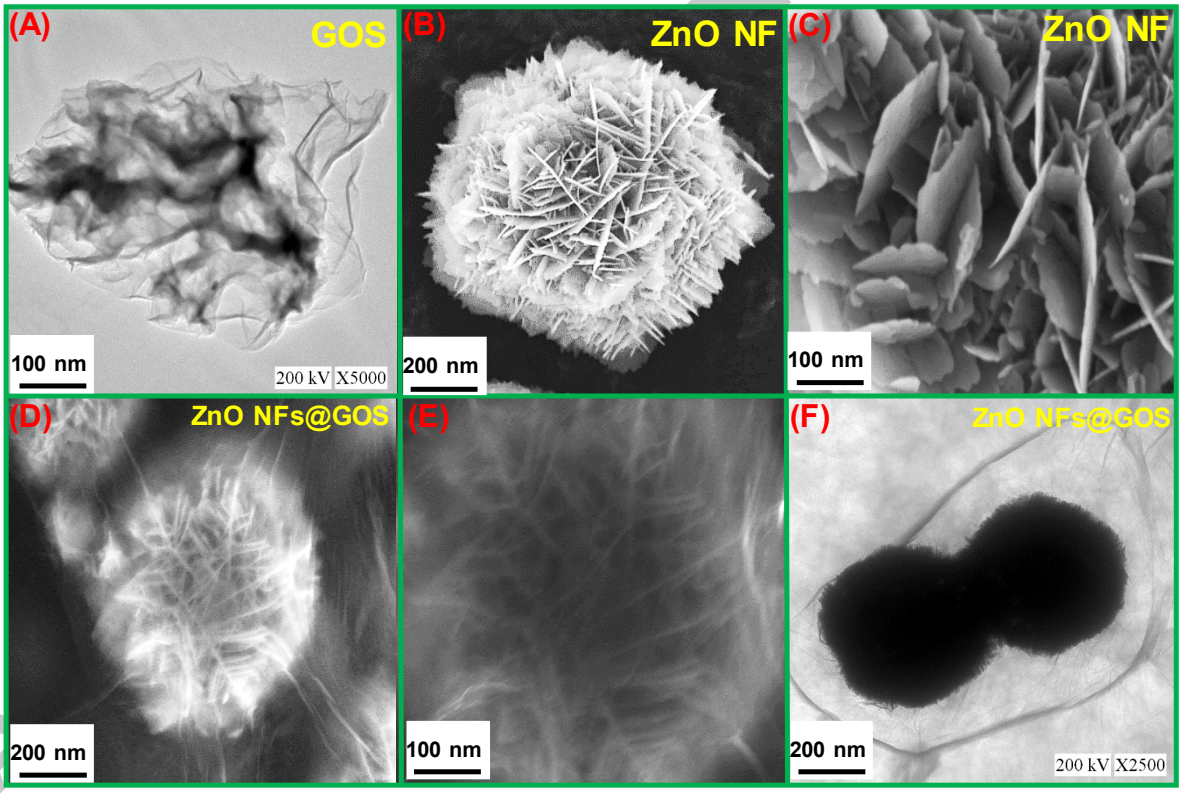


Figure 1. HRTEM images of GOS (A) and FESEM images of ZnO NFs (B-C). FESEM images of ZnO NFs@GOS (D-E) and HR-TEM images of nanocomposite (F).

3. Results and discussion

3.1. Structural investigations of the ZnO NFs@GOS nanocomposite

The surface morphology of the flower based and GOS covered nanocomposite has investigated by FESEM and HRTEM analysis. In **Figure 1A**, show that the HRTEM of graphene oxide nanosheets and its paper like layered bulk-sheets. A sonochemically synthesized ZnO is shows FESEM in **Figure 1B-C**. The ZnO particles is flower like nanostructure. The surface morphology of the as-synthesized ZnO NFs@GOS nanocomposite was analyzed by FESEM and HRTEM in **Figure D-F**. The graphene oxide nanosheets wrapped and covered ZnO nanoflower was examined by FESEM in **Figure D-E**. As HRTEM shows that the flowers like structure was observed for the synthesized ZnO with GOS. These FESEM and HRTEM results are confirmed that the formation of hierarchical nanocomposite.

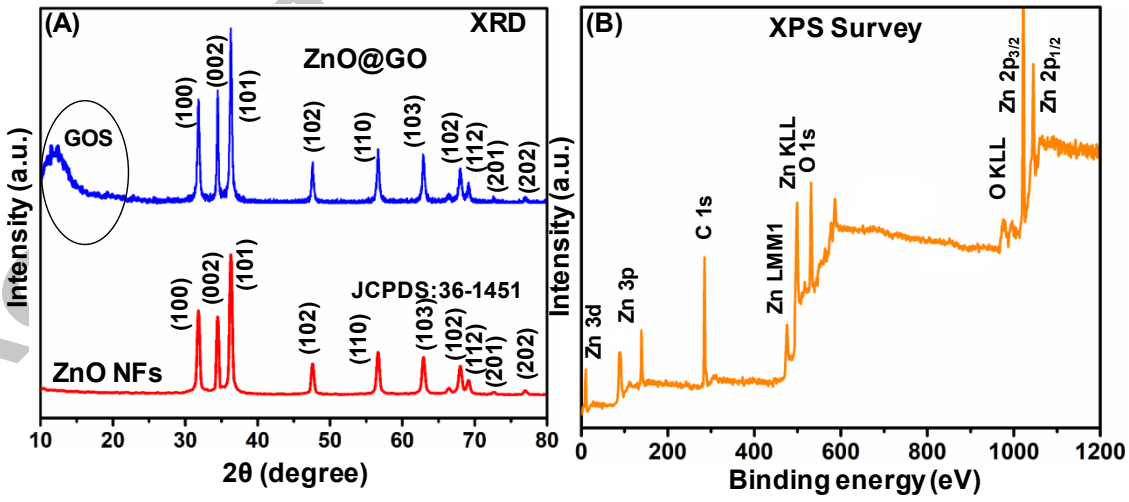


Figure 2. XRD analysis of ZnO NFs and ZnO NFs@GOS nanocomposite (A). XPS survey spectrum of nanocomposite (B).

The XRD patterns of ZnO NFs and ZnO NFs@GOS were displayed in **Figure 2A**. The XRD pattern of the ZnO NFs@GOS shows that the several diffraction peaks are observed and these are correlated to the hexagonal plane according to the JCPDS No. 36-1451 of the ZnO NFs [39, 40]. Therefore, the XRD peaks are indicates that the formation of ZnO catalyst. Furthermore, the GOS peaks exhibited the diffraction of the nanocomposite assigned for the miller indices plane is (002) [41-45]. Finally, this information's are indicated formation of the ZnO NFs@GOS nanocomposite.

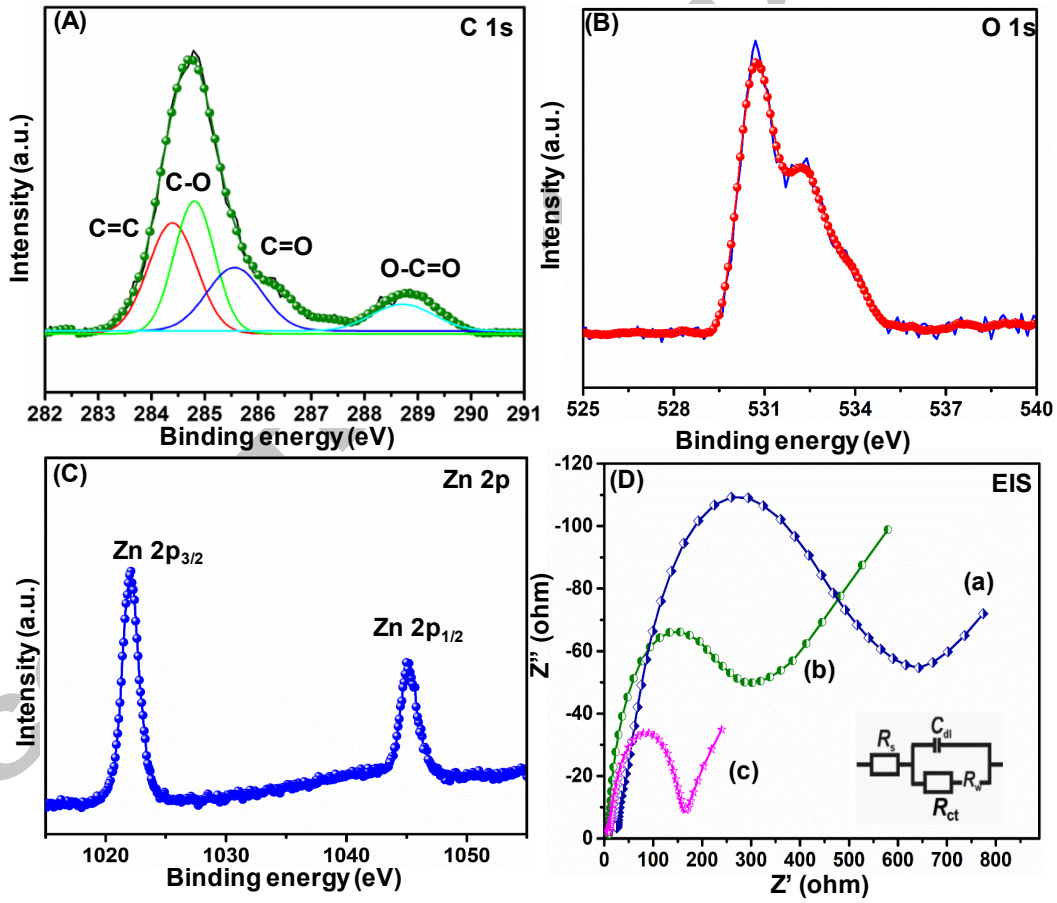


Figure 3. XPS spectrum of C 1s (A), O 1s (B) and Zn 2P (C). EIS analysis of GOS/SPCE (a), ZnO NFs/SPCE (b) and ZnO NFs@GOS/SPCE (c) in (D) 0.1 M KCl containing 5 mM $[Fe(CN)_6]^{-3/-4}$ solution.

In addition, examine the chemical compositions and electronic states of the GOS based nanocomposite, the XPS analysis was studied and are showed in **Figure 2B and 3A-C.** In Figure 2B, shows the XPS survey analysis of the ZnO NFs@GOS nanocomposite. The carbon (C 1s), oxygen (O 1s) and zinc (Zn 2p) content in the ZnO NFs@GOS were observed at their correlated binding energies [46, 47]. The XPS high-resolution C 1s spectrum (Figure 3A) shows the major peak due to ring carbon. In Figure 3B**,** the XPS spectrum of the O 1s present in the ZnO reveals the primary peak denotes the Zn-O bond located at 530.7 eV, which demonstrate the oxygen present in the form of bridging with Zn atom and GOS. As shown in Figure 3C, two dominant peaks of Zn 2p bounded with the metals that exhibited the Zn $2p_{3/2}$ and Zn $2p_{1/2}$ located at the (1021.5 eV) and (1045.2 eV) [46]. The XPS study reveals that the ZnO NFs@GOS nanocomposite formation by a sonochemical method.

3.2. Electrochemical characterization of ZnO NFs@GOS modified electrode

The electrochemical characterization of the unmodified and modified electrodes is analyzed by electrochemical impedance spectroscopy (EIS). In Figure 3D, shows the Nyquist diagram of the diverse modified electrodes as GOS/SPCE (a), ZnO NFs/SPCE (b) and ZnO NFs@GOS/SPCE (c) in 0.1 M KCl containing 5 mM $[Fe(CN)_6]^{-3/-4}$ solution (frequency ranges of 100 MHz to 100 kHz). For the comparison, the GOS/SPCE and ZnO NFs/SPCE shows the higher R_{ct} value around 592.6 Ω and 286.48 Ω, respectively. The smallest semicircle was observed for the ZnO NFs@GOS modified SPCE indicating advantages of the

composition and electrostatic attraction between ZnO NF and GOS, which resulted in the lowest Rct value (128.45 Ω) for the nanocomposite-modified nanocomposite.

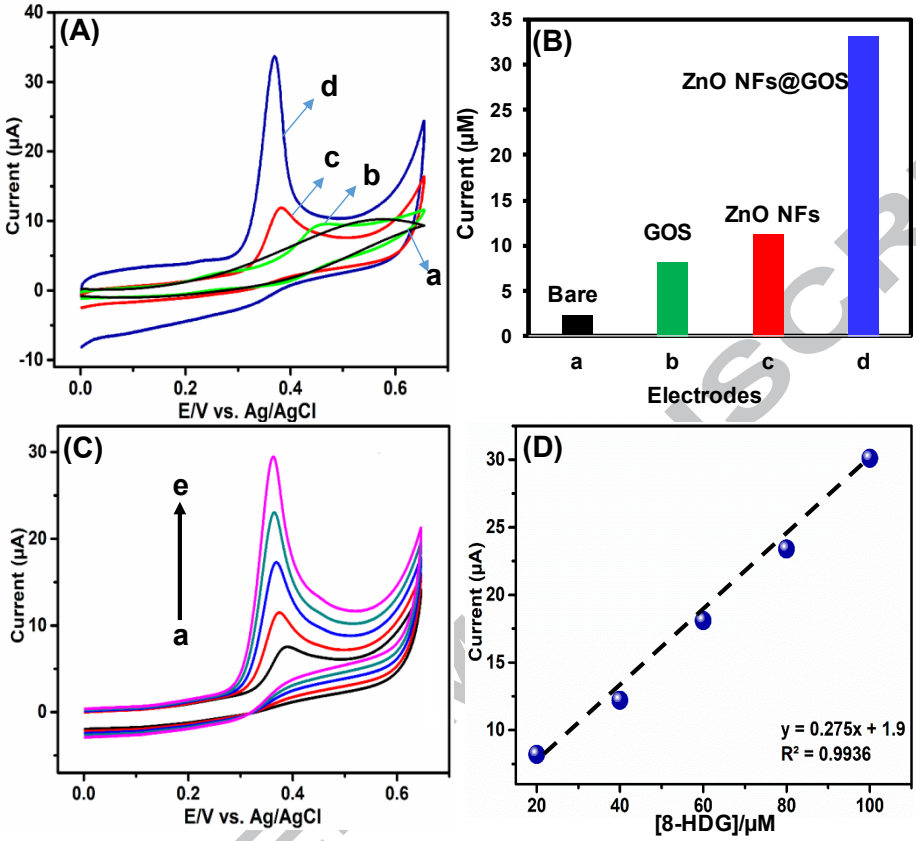
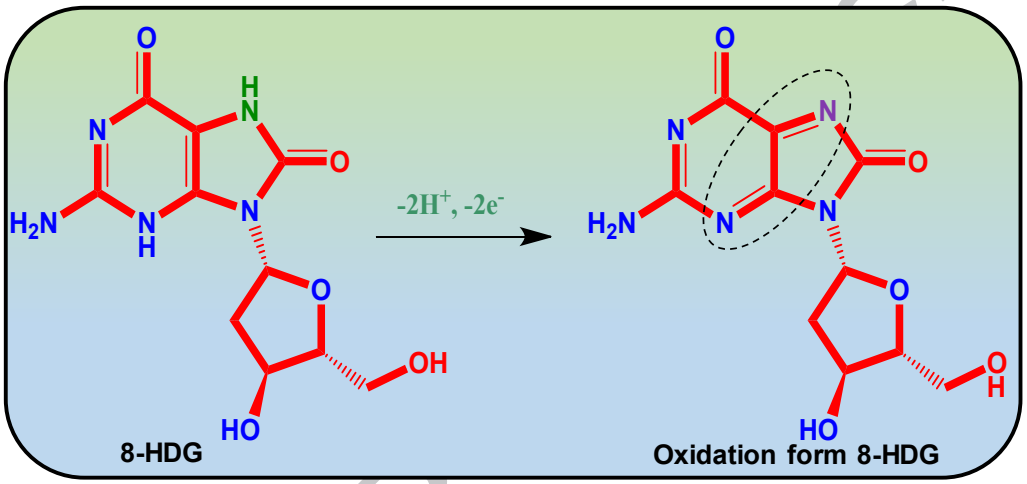


Figure 4. (A) CVs of bare SPCE (a), GOS/SPCE (b), ZnO NFs/SPCE (c) and ZnO NFs@GOS/SPCE (d) containing 100 µM 8-HDG in 0.05 M phosphate buffer at the scan rate at 50 mV/s and (B) electrodes versus peak currents (n=3). (C) Increasing concentration of 8-HDG (20 to 100 µM) in 0.05 M phosphate buffer at ZnO NFs@GOS/SPCE (n=3). (D) Shows the plot between [8-HDG]/µM versus anodic peak current/µA.

3.3. Electrocatalytic performances of ZnO NFs@GOS/SPCE towards 8-HDG

The CV method **(Figure 4A)** was utilized to examine the electrochemical performance of bare SPCE (a), GOS/SPCE (b), ZnO NFs/SPCE (c) and ZnO NFs@GOS/SPCE in 0.05 M phosphate buffer with a pH of 7.0 in the presence of 8-HDG (100 µM). The scan rate was 50

mV/s and the potential is 0 to 0.65 V. The bare SPCE shows the very low intensity towards the oxidation of 8-HDG. Furthermore, the SPCEs were modified with GOS and ZnO NFs, the oxidation peak currents were increased towards the biomarker **(Figure 4B)**. Nevertheless, the ZnO NFs@GOS modified SPCE shows the high peak current of 33.84 µA towards 8-HDG (100 µM). Moreover, the electrochemical oxidation mechanism of 8-HDG is given in **Scheme 2** and the biomarker is converted into oxidation form of 8-HDG.



Scheme 2. The plausible electrochemical-oxidation reaction of 8-HDG biomarker based on ZnO NFs@GOS/SPCE.

Due to the high surface area and excellent electrocatalytic ability of the ZnO NFs@GOS in pH 7.0, 8-HDG was oxidized by electrochemical method. Furthermore, the electrocatalytic performance of the nanocomposite was checked towards the 8-HDG oxidation by adding the different concentrations in 0.05 M phosphate buffer. As shown in **Figure 4C**, the anodic peak current was increased linearly for the increasing concentration 8-HDG from 20 to 100 µM. In addition, the oxidation linear regression equation y= 0.275x 1.9 with the correlation co-efficient of R^2= 0.9936 in **Figure 4D**. Therefore, the results strongly

suggest that the ZnO NFs@GOS modified SPCE accelerate electron transfer significantly towards the oxidation of 8-HDG.

The influences of the scan rate were also studied in the range of 10 to 120 mV/s on ZnO NFs@GOS modified SPCE in the presence of 100 µM 8-HDG (**Figure 5A**). With increase of the scan rate, the intensities of currents also increased. Therefore, **Figure 5B,** shows the current is proportional to the square root of the scan rate. Moreover, the obtained anodic peak current values are plotted against the different scan rates. As shown in **Figure 5B**, anodic peak currents were linearly proportional to square root of the scan rates with the correlation coefficient of R^2=0.9971 was observed for anodic peak currents. These results clearly indicated that the electro-oxidation of biomarker (8-HDG) at ZnO NFs@GOS modified SPCE is controlled by the diffusion process [48, 49].

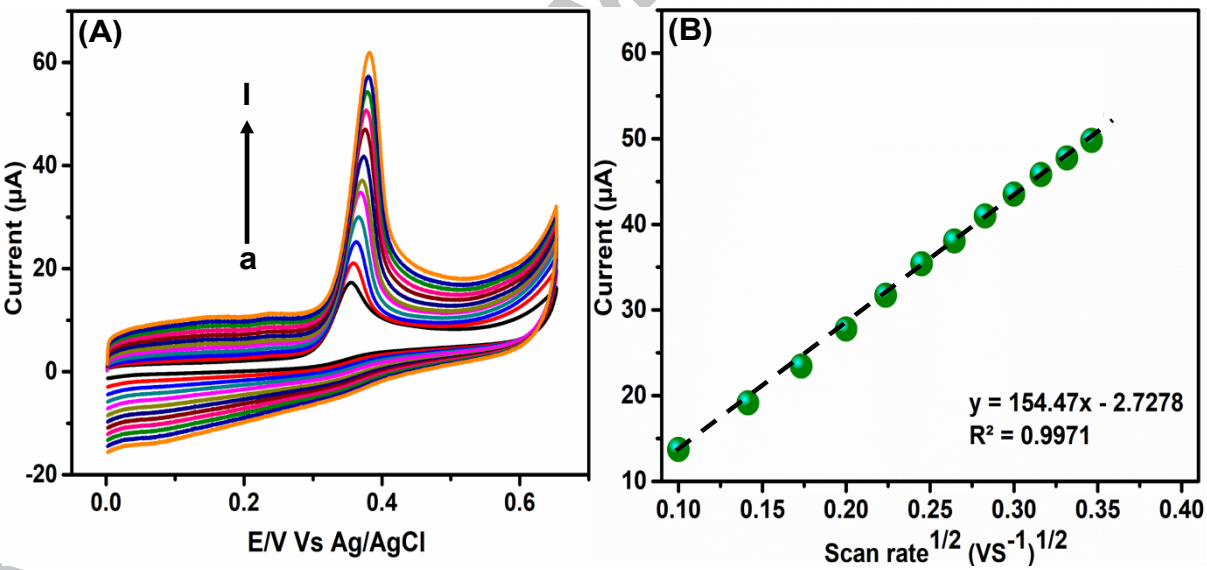


Figure 5. (A) CV curves of different scan rate study ranges from (10 to 120 mV/s) on ZnO NFs@GOS/SPCE for the reduction of 100 µM 8-HDG in 0.05 M phosphate buffer (n=3). (B) The calibration plot between the anodic peak current (I_{pa}) against the square root of the scan rates.

The pH analysis is a crucial study that affects the electrochemical response of the analyte. In this way, the impact of the pH have been explored. In Figure S1A, shows the plot of different pH 3.0 to 11.0 in presence of 100 µM 8-HDG. It can be seen that the anodic peak current response was increased form pH 3.0 to pH 7.0 and then it gradually decreases from pH 7.0 to pH 11.0. In addition, the peak potential was shifted to negative side with an increase in the pH value of the supporting electrolyte from 3.0 to 11.0 (Figure S1B). The linear regression equations were deduced as E_{pa} = 0.053 pH+0.64 (R^2=0.9983) for 8-HDG, which are close to the theoretical Nernst value (59.0 mV) for an equal number of electrons and protons involved in the electrochemical oxidation.

3.4. Determination of 8-HDG by amperometric (i-t) technique on ZnO NFs@GOS/SPCE

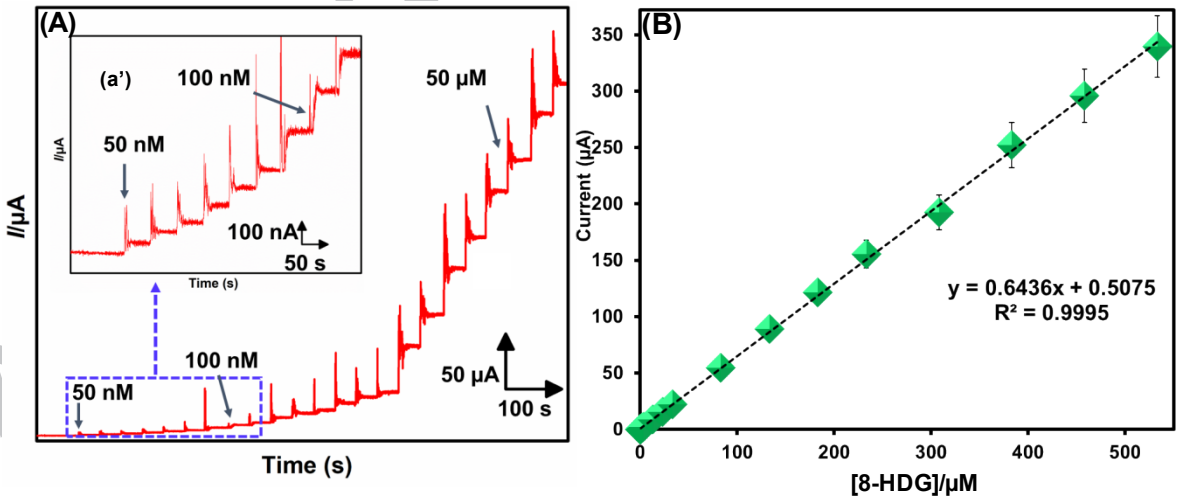


Figure 6. (A) Amperometric responses for the successive additions of 8-HDG in 0.05 M phosphate buffer (pH 7.0) and various concentration ranges from (0.05 to 536.5 µM) at ZnO

NFs@GOS/SPCE and (inset) low concentration ranges. (B) The linear plot of 8-HDG concentrations versus peak current.

The amperometric technique was performed for analyzing the electrocatalytic performance of ZnO NFs@GOS modifed electrode towards biomarker. The analytical performance of biomarker (8-HDG) was performed on the ZnO NFs@GOS modified electrode in 0.05 M phosphate buffer (pH 7.0) at the fixed potential is 0.36 V. In Figure 6A, shows that the ZnO NFs@GOS establishes a linear relationship ranges from 50 nM to 536.5 μM with a regression coefficient of 0.9995. In Figure 6A (inset), shows the amperometric peaks of the lower concentration of 8-HDG. Moreover, the obtained peak current values were plotted against the different concentrations of 8-HDG and the results are displayed in Figure 6B. Furthermore, the linear regression equation is I_{pa}= 0.6436 [8-HDG]+0.5075. The low and high concentrations of biomarker shows good linear response was increased for each addition of 8-HDG. Furthermore, the limit of detection (LOD) and sensitivity of ZnO NFs@GOS modified electrode are 36.67 nM and 9.064 μA μM^{-1} cm^{-2}, respectively. The limit of quantitation (LOQ) is calculated as 49.5 nM. Furthermore, the results were compared with previous literatures in **Table 1.** These results confirm that the impressive electrochemical performance of the proposed ZnO NFs@GOS modified electrode towards 8-HDG sensing.

Table 1. Comparison of analytical parameters with previous articles

Electrode	LOD (nM)	Linear range (μM)	Ref.
Single-walled carbon nanotubes/Lysine	97.0	0.3–10.0	[50]
Multi-walled carbon nanotubes/ polyethylenimine	100.0	0.5–30.0	[51]
Multi-walled carbon nanotubes/GOS	350.0	3.0–75.0	[52]

poly(3-methylthiophene)	100.0	0.7–70.0	[53]
graphene/nafion	120.0	0.07–33.04	[54]
graphene nanosheets	80.75	0.056–36.155	[55]
ZnO NFs@GOS	36.67	0.05–536.5	This work

3.5. Selectivity, stability and reproducibility of the sensor

In order to study the selectivity of the ZnO NFs@GOS modified electrode, the amperometric was performed towards the different biologically important biomolecules. In **Figure 7A**, exhibited the amperometric responses for the additions of 0.3 mM of hydrogen peroxide (H_2O_2), glucose (Glu), ascorbic acid (AA), folic acid (FA), uric acid (UA), dopamine (DA), serotonin (SN), vanillin (VN) and epinephrine (EP) in presence of 0.05 mM of 8-HDG. It is found that there is minor response towards other biomolecules. Therefore, these results indicating that the ZnO NFs@GOS modified electrode has great towards the 8-HDG sensing.

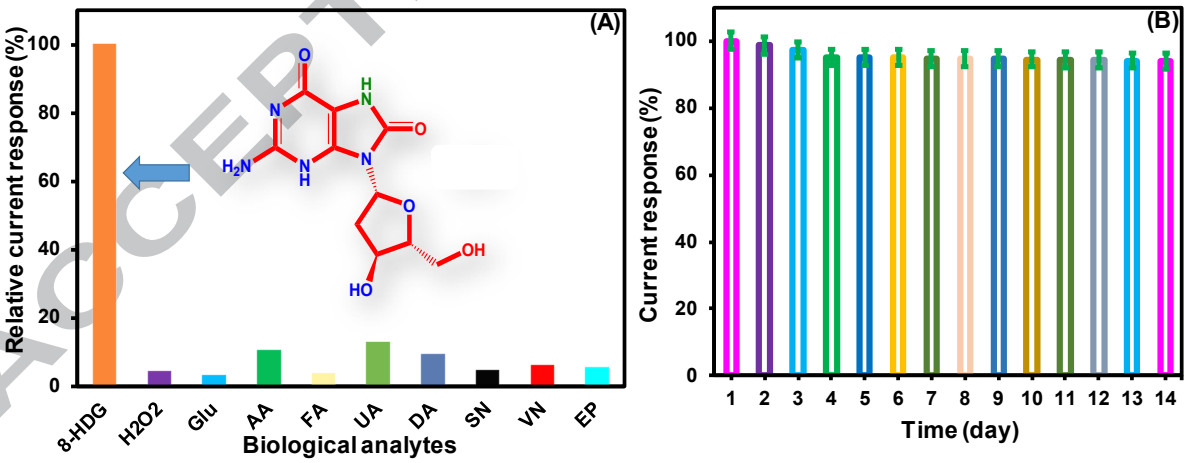


Figure 7. (A) Amperometric selective responses of ZnO NFs@GOS modified electrode towards 0.05 mM of 8-HDG with 0.3 mM of interfering compounds (n=3). (B) Stability of the sensor as its continuous usage for 14 days containing 100 μM 8-HDG.

In addition, the stability of the ZnO NFs@GOS modified electrode was explored by amperometric technique. **Figure 7B** shows the amperometric current response for the addition of 100 μM 8-HDG in 0.05 M phosphate buffer (pH 7.0) at ZnO NFs@GOS modified electrode. The stability study shows that the initial peak current value of the 8-HDG oxidation was decreased, but its only 3.76% on 14 days. For the reproducibility analysis seven different ZnO NFs@GOS modified were prepared and the amperometric response were recorded in presence of 100 μM of 8-HDG. The obtained results were given in **Figure S2** and the relative standard deviation (RSD) value were calculated to be 3.42%. The repeatability was tested for ten times and the RSD value were calculated to be 3.64% (**Figure S3)**. Therefore, these results of ZnO NFs@GOS modified electrode shows the excellent selectivity, stability and reproducibility towards the detection of 8-HDG sensing.

Table 2. Determination of 8-HDG in real samples based on ZnO NFs@GOS modified electrode

Real Samples	Added/nM	Found/nM	Recovery/%	*RSD/%
Urine samples 1	0	68.36	-	2.94
	200	192.78	96.39	3.52
Urine samples 2	0	79.02	-	3.06
	200	189.78	97.44	3.72

Urine samples 3	0	58.42	-	3.37
	200	193.15	96.57	3.61

* Related standard deviation (RSD) of n=3 independent experiments.

3.6. Real sample analysis

To further evaluate the practicality of the ZnO NFs@GOS modified electrode was investigated in various urine samples. The urine samples were analyzed directly and the diluted with buffer and spiked with a specified concentration of 8-HDG by using the standard addition method. Amperometric responses for the addition of human urine samples spiked with 200 nM concentration of 8-HDG. Then, the peak current responses were increased for each addition of 8-HDG spiked samples. The obtained peak current responses have calculated against the concentration. Moreover, the RSD (n=3) results were calculated and tabulated in **Table 2**. These results clearly reveals that the practical feasibility of the ZnO NFs@GOS proposed sensor towards 8-HDG sensing.

4. Conclusion

In conclusion, an efficient and effective nanocatalyst for non-enzymatic biosensor based on ZnO NFs@GOS nanocomposite has been developed by sonochemical method. As-prepared ZnO NFs@GOS nanocomposite was used to fabricate the modified electrodes for the determination cancer toxic marker. The electrocatalytic activity of the ZnO NFs@GOS for the detection of 8-HDG was evaluated using CV and amperometric methods. The fabricated amperometric sensor exhibits outstanding electrochemical performance for 8-HDG oxidation. Its shows wide linear range 0.05 to 536.5 μM and lowest LOD (36. 67 nM)

towards 8-HDG sensing. Importantly, ZnO NFs@GOS modified sensor could be successfully demonstrated the practicality of the electrodes performance in urine samples.

Acknowledgments

Financial assistance received from National Taipei University of Technology is gratefully acknowledged. One of the author Dr. Govindasamy Mani would like to gratitude National Taipei University of technology for the post-doctoral fellowship.

References

[1] M. Govindasamy, B. Subramanian, S.-F. Wang, S. Chinnapaiyan, R.J. Ramalingam, H. Al-lohedan, Ultrasound-Assisted Synthesis of Tungsten Trioxide Entrapped with Graphene Nanosheets for Developing Nanomolar Electrochemical (Hormone) Sensor and Enhanced Sensitivity of the Catalytic Performance, Ultrasonics Sonochemistry, 56 (2019) 134-142.

[2] M. Govindasamy, S.-F. Wang, W.C. Pan, B. Subramanian, R.J. Ramalingam, H. Al-lohedan, Facile sonochemical synthesis of perovskite-type $SrTiO_3$ nanocubes with reduced graphene oxide nanocatalyst for an enhanced electrochemical detection of α-amino acid (tryptophan), Ultrasonics Sonochemistry, 56 (2019) 193-199.

[3] M. Govindasamy, S.-F. Wang, S. Kumaravel, R.J. Ramalingam, H.A. Al-lohedan, Facile synthesis of copper sulfide decorated reduced graphene oxide nanocomposite for high sensitive detection of toxic antibiotic in milk, Ultrasonics sonochemistry, 52 (2019) 382-390.

[4] M. Govindasamy, S. Shanthi, E. Elaiyappillai, S.-F. Wang, P.M. Johnson, H. Ikeda, Y. Hayakawa, S. Ponnusamy, C. Muthamizhchelvan, Fabrication of hierarchical $NiCo_2S_4$@ CoS_2 nanostructures on highly conductive flexible carbon cloth substrate as a hybrid electrode material for supercapacitors with enhanced electrochemical performance, Electrochimica Acta, 293 (2019) 328-337.

[5] L. Vayssieres, Growth of arrayed nanorods and nanowires of ZnO from aqueous solutions, Advanced Materials, 15 (2003) 464-466.

[6] S.-M. Chen, S. Manavalan, U. Rajaji, M. Govindasamy, T.-W. Chen, M.A. Ali, A.K. Alnakhli, F.M. Al-Hemaid, M. Elshikh, Determination of the antioxidant propyl gallate in meat by using a screen-printed electrode modified with CoSe2 nanoparticles and reduced graphene oxide, Microchimica Acta, 185 (2018) 520.

[7] U. Rajaji, K. Murugan, S.-M. Chen, M. Govindasamy, T.-W. Chen, P.H. Lin, Graphene oxide encapsulated 3D porous chalcopyrite (CuFeS2) nanocomposite as an emerging electrocatalyst for agro-hazardous (methyl paraoxon) detection in vegetables, Composites Part B: Engineering, 160 (2019) 268-276.

[8] U. Rajaji, M. Govindasamy, S.-M. Chen, T.-W. Chen, X. Liu, S. Chinnapaiyan, Microwave-assisted synthesis of Bi2WO6 flowers decorated graphene nanoribbon composite for electrocatalytic sensing of hazardous dihydroxybenzene isomers, Composites Part B: Engineering, 152 (2018) 220-230.

[9] S.-M. Chen, R. Umamaheswari, G. Mani, T.-W. Chen, M.A. Ali, A.-H. Fahad, M. Elshikh, M.A. Farah, Hierarchically structured CuFe2O4 ND@RGO composite for the detection of oxidative stress biomarker in biological fluids, Inorganic Chemistry Frontiers, 5 (2018) 944-950.

[10] M. Govindasamy, U. Rajaji, S.-M. Chen, S. Kumaravel, T.-W. Chen, F.M. Al-Hemaid, M.A. Ali, M.S. Elshikh, Detection of pesticide residues (Fenitrothion) in fruit samples based on niobium carbide@ molybdenum nanocomposite: an electrocatalytic approach, Analytica chimica acta, 1030 (2018) 52-60.

[11] S. Manavalan, M. Govindasamy, S.-M. Chen, U. Rajaji, T.-W. Chen, M.A. Ali, F.M. Al-Hemaid, M. Elshikh, M.A. Farah, Reduced graphene oxide supported raspberry-like SrWO4 for sensitive detection of catechol in green tea and drinking water samples, Journal of the Taiwan Institute of Chemical Engineers, 89 (2018) 215-223.

[12] K. Sakthivel, G. Mani, S.-M. Chen, S.-H. Lin, A. Muthumariappan, V. Mani, A novel synthesis of non-aggregated spinel nickel ferrite nanosheets for developing non-enzymatic reactive oxygen species sensor in biological samples, Journal of Electroanalytical Chemistry, 820 (2018) 161-167.

[13] V.K. Ponnusamy, V. Mani, S.-M. Chen, W.-T. Huang, J.-F. Jen, Rapid microwave assisted synthesis of graphene nanosheets/polyethyleneimine/gold nanoparticle composite

and its application to the selective electrochemical determination of dopamine, Talanta, 120 (2014) 148-157.

[14] N. Jeromiyas, E. Elaiyappillai, A.S. Kumar, S.-T. Huang, V. Mani, Bismuth nanoparticles decorated graphenated carbon nanotubes modified screen-printed electrode for mercury detection, Journal of the Taiwan Institute of Chemical Engineers, 95 (2019) 466-474.

[15] T.-W. Chen, U. Rajaji, S.-M. Chen, R.J. Ramalingam, X. Liu, Developing Green Sonochemical Approaches towards the Synthesis of Highly Integrated and Interconnected Carbon Nanofiber Decorated with Sm2O3 Nanoparticles and their use in the Electrochemical Detection of Toxic 4-nitrophenol, Ultrasonics Sonochemistry, (https://doi.org/10.1016/j.ultsonch.2019.05.012) (2019).

[16] P. Mayuri, S.-T. Huang, V. Mani, A.S. Kumar, A new organic redox species-indole tetraone trapped MWCNT modified electrode prepared by in-situ electrochemical oxidation of indole for a bifunctional electrocatalysis and simultaneous flow injection electroanalysis of hydrazine and hydrogen peroxide, Electrochimica Acta, 268 (2018) 150-162.

[17] F. Oba, A. Togo, I. Tanaka, J. Paier, G. Kresse, Defect energetics in ZnO: A hybrid Hartree-Fock density functional study, Physical Review B, 77 (2008) 245202.

[18] V. Mani, S. Shanthi, T.-K. Peng, H.-Y. Lin, H. Ikeda, Y. Hayakawa, S. Ponnusamy, C. Muthamizhchelvan, S.-T. Huang, Real-time quantification of hydrogen peroxide production in living cells using NiCo2S4@ CoS2 heterostructure, Sensors and Actuators B: Chemical, 287 (2019) 124-130.

[19] M. Keerthi, M. Akilarasan, S.-M. Chen, S. Kogularasu, M. Govindasamy, V. Mani, M.A. Ali, F.M. Al-Hemaid, M. Elshikh, One-Pot Biosynthesis of Reduced Graphene Oxide/Prussian Blue Microcubes Composite and Its Sensitive Detection of Prophylactic Drug Dimetridazole, Journal of The Electrochemical Society, 165 (2018) B27-B33.

[20] V. Mani, M. Govindasamy, S.-M. Chen, R. Karthik, S.-T. Huang, Determination of dopamine using a glassy carbon electrode modified with a graphene and carbon nanotube hybrid decorated with molybdenum disulfide flowers, Microchimica Acta, 183 (2016) 2267-2275.

[21] M. Govindasamy, S.-M. Chen, V. Mani, R. Devasenathipathy, R. Umamaheswari, K.J. Santhanaraj, A. Sathiyan, Molybdenum disulfide nanosheets coated multiwalled carbon

nanotubes composite for highly sensitive determination of chloramphenicol in food samples milk, honey and powdered milk, Journal of colloid and interface science, 485 (2017) 129-136.

[22] M. Govindasamy, V. Mani, S.-M. Chen, T.-W. Chen, A.K. Sundramoorthy, Methyl parathion detection in vegetables and fruits using silver@graphene nanoribbons nanocomposite modified screen printed electrode, Scientific reports, 7 (2017) 46471.

[23] M. Govindasamy, S. Manavalan, S.-M. Chen, R. Umamaheswari, T.-W. Chen, Determination of oxidative stress biomarker 3-nitro-L-tyrosine using CdWO4 nanodots decorated reduced graphene oxide, Sensors and Actuators B: Chemical, 272 (2018) 274-281.

[24] M. Govindasamy, S. Manavalan, S.-M. Chen, U. Rajaji, T.-W. Chen, F.M. Al-Hemaid, M.A. Ali, M.S. Elshikh, Determination of Neurotransmitter in Biological and Drug Samples Using Gold Nanorods Decorated f-MWCNTs Modified Electrode, Journal of The Electrochemical Society, 165 (2018) B370-B377.

[25] G. Boopathy, M. Keerthi, S.-M. Chen, M. Umapathy, M. Govindasamy, T.-W. Chen, M.A. Ali, F.M. Al-Hemaid, M. Elshikh, Graphene Oxide/α-MnO2 Binary Nanosheets Based Non-Enzymatic Biosensor for Pico-Molar Level Electrochemical Detection of Biomarker (Guanine) in DNA Sample, Journal of The Electrochemical Society, 165 (2018) B651-B658.

[26] R. Madhu, B. Dinesh, S.-M. Chen, R. Saraswathi, V. Mani, An electrochemical synthesis strategy for composite based ZnO microspheres–Au nanoparticles on reduced graphene oxide for the sensitive detection of hydrazine in water samples, RSC Advances, 5 (2015) 54379-54386.

[27] M. Govindasamy, S.-M. Chen, V. Mani, M. Akilarasan, S. Kogularasu, B. Subramani, Nanocomposites composed of layered molybdenum disulfide and graphene for highly sensitive amperometric determination of methyl parathion, Microchimica Acta, 184 (2017) 725-733.

[28] V. Mani, M. Govindasamy, S.-M. Chen, B. Subramani, A. Sathiyan, J.P. Merlin, Determination of folic acid using graphene/molybdenum disulfide nanosheets/gold nanoparticles ternary composite, Int. J. Electrochem. Sci, 12 (2017) e267.

[29] V. Mani, M. Govindasamy, S.-M. Chen, B. Subramani, A. Sathiyan, J.P. Merlin, Determination of Folic Acid Using Graphene/Molybdenum Disulfide Nanosheets/Gold Nanoparticles Ternary Composite, Int. J. Electrochem. Sci, 12 (2017) 258-267.

[30] M. Khan, X. Liu, Y. Tang, X. Liu, Ultra-sensitive electrochemical detection of oxidative stress biomarker 8-hydroxy-2′-deoxyguanosine with poly (L-arginine)/graphene wrapped Au nanoparticles modified electrode, Biosensors and Bioelectronics, 117 (2018) 508-514.

[31] Y. Lv, S. Chen, Y. Shen, J. Ji, Q. Zhou, S. Liu, Y. Zhang, Competitive multiple-mechanism-driven electrochemiluminescent detection of 8-hydroxy-2′-deoxyguanosine, Journal of the American Chemical Society, 140 (2018) 2801-2804.

[32] T. Shang, P. Wang, X. Liu, X. Jiang, Z. Hu, X. Lu, Facile synthesis of porous single-walled carbon nanotube for sensitive detection of 8-Hydroxy-2′-deoxyguanosine, Journal of Electroanalytical Chemistry, 808 (2018) 28-34.

[33] G. Cao, C. Wu, Y. Tang, C. Wan, Ultrasmall HKUST-1 nanoparticles decorated graphite nanosheets for highly sensitive electrochemical sensing of DNA damage biomarker 8-hydroxy-2'-deoxyguanosine, Analytica Chimica Acta, (2019).

[34] L.-P. Jia, L.-J. Wang, R.-N. Ma, L. Shang, W. Zhang, Q.-W. Xue, H.-S. Wang, An electrochemical aptasensor for the highly sensitive detection of 8-hydroxy-2′-deoxyguanosine based on the hybridization chain reaction, Talanta, 179 (2018) 414-419.

[35] J. Hao, K. Wu, C. Wan, Y. Tang, Reduced graphene oxide-ZnO nanocomposite based electrochemical sensor for sensitive and selective monitoring of 8-hydroxy-2′-deoxyguanosine, Talanta, 185 (2018) 550-556.

[36] J. Zheng, T. Gao, H. Shi, Y. Huang, Y. Xiang, G. Li, Electrochemical analysis of 8-hydroxy-2'-deoxyguanosine with enhanced sensitivity based on exonuclease-mediated functional nucleic acid, Talanta, (2019).

[37] S. Manavalan, U. Rajaji, S.-M. Chen, S.S.P. Selvin, M. Govindasamy, T.-W. Chen, M.A. Ali, F.M. Al-Hemaid, M. Elshikh, Determination of 8-hydroxy-2′-deoxyguanosine oxidative stress biomarker using dysprosium oxide nanoparticles@reduced graphene oxide, Inorganic Chemistry Frontiers, 5 (2018) 2885-2892.

[38] A.K. Zak, H. Wang, R. Yousefi, A.M. Golsheikh, Z. Ren, Sonochemical synthesis of hierarchical ZnO nanostructures, Ultrasonics sonochemistry, 20 (2013) 395-400.

[39] H. Li, J. Wang, H. Liu, H. Zhang, X. Li, Zinc oxide films prepared by sol–gel method, Journal of Crystal Growth, 275 (2005) e943-e946.

[40] Y. Wang, M. Li, Hydrothermal synthesis of single-crystalline hexagonal prism ZnO nanorods, Materials letters, 60 (2006) 266-269.

[41] V. Mani, R. Devasenathipathy, S.-M. Chen, B. Subramani, M. Govindasamy, A Novel Glucose Biosensor at Glucose Oxidase Immobilized Graphene and Bismuth Nanocomposite Film Modified Electrode, International Journal of Electrochemical Science, 10 (2015) 691-700.

[42] M. Govindasamy, V. Mani, S.-M. Chen, R. Karthik, K. Manibalan, R. Umamaheswari, MoS2 Flowers Grown on Graphene/Carbon Nanotubes: a Versatile Substrate for Electrochemical Determination of Hydrogen Peroxide, International Journal of Electrochemical Science, 11 (2016) 2954-2961.

[43] V. Mani, B. Devadas, S.-M. Chen, Direct electrochemistry of glucose oxidase at electrochemically reduced graphene oxide-multiwalled carbon nanotubes hybrid material modified electrode for glucose biosensor, Biosensors and Bioelectronics, 41 (2013) 309-315.

[44] R. Devasenathipathy, V. Mani, S.-M. Chen, Highly selective amperometric sensor for the trace level detection of hydrazine at bismuth nanoparticles decorated graphene nanosheets modified electrode, Talanta, 124 (2014) 43-51.

[45] B. Unnikrishnan, V. Mani, S.-M. Chen, Highly sensitive amperometric sensor for carbamazepine determination based on electrochemically reduced graphene oxide–single-walled carbon nanotube composite film, Sensors and Actuators B: Chemical, 173 (2012) 274-280.

[46] S. Aksoy, Y. Caglar, S. Ilican, M. Caglar, Sol–gel derived Li–Mg co-doped ZnO films: Preparation and characterization via XRD, XPS, FESEM, Journal of Alloys and Compounds, 512 (2012) 171-178.

[47] V. Mani, R. Devasenathipathy, S.-M. Chen, J.-A. Gu, S.-T. Huang, Synthesis and characterization of graphene-cobalt phthalocyanines and graphene-iron phthalocyanine composites and their enzymatic fuel cell application, Renewable Energy, 74 (2015) 867-874.

[48] S. Kogularasu, M. Govindasamy, S.-M. Chen, M. Akilarasan, V. Mani, 3D graphene oxide-cobalt oxide polyhedrons for highly sensitive non-enzymatic electrochemical determination of hydrogen peroxide, Sensors and Actuators B: Chemical, 253 (2017) 773-783.

[49] A.E. Vilian, V. Mani, S.-M. Chen, B. Dinesh, S.-T. Huang, The immobilization of glucose oxidase at manganese dioxide particles-decorated reduced graphene oxide sheets for

the fabrication of a glucose biosensor, Industrial & Engineering Chemistry Research, 53 (2014) 15582-15589.

[50] A. Gutiérrez, F.A. Gutierrez, M. Eguílaz, J.M. González-Domínguez, J. Hernández-Ferrer, A. Ansón-Casaos, M.T. Martínez, G.A. Rivas, Electrochemical sensing of guanine, adenine and 8-hydroxy-2′-deoxyguanosine at glassy carbon modified with single-walled carbon nanotubes covalently functionalized with lysine, RSC Advances, 6 (2016) 13469-13477.

[51] A. Gutiérrez, S. Gutiérrez, G. García, L. Galicia, G.A. Rivas, Determinatiom of 8-Hydroxy 2′-Deoxyguanosine Using Electrodes Modified with a Dispersion of Carbon Nanotubes in Polyethylenimine, Electroanalysis, 23 (2011) 1221-1228.

[52] R.N. Goyal, Determination of 8-Hydroxydeoxyguanosine: A potential biomarker of oxidative stress, using carbon-allotropic nanomaterials modified glassy carbon sensor, Talanta, 161 (2016) 735-742.

[53] T.-H. Li, W.-L. Jia, H.-S. Wang, R.-M. Liu, Electrochemical performance of 8-hydroxy-2′-deoxyguanosine and its detection at poly (3-methylthiophene) modified glassy carbon electrode, Biosensors and Bioelectronics, 22 (2007) 1245-1250.

[54] L. Jia, H. Wang, Electrochemical reduction synthesis of graphene/Nafion nanocomposite film and its performance on the detection of 8-hydroxy-2′-deoxyguanosine in the presence of uric acid, Journal of Electroanalytical Chemistry, 705 (2013) 37-43.

[55] L.-P. Jia, J.-F. Liu, H.-S. Wang, Electrochemical performance and detection of 8-Hydroxy-2′-deoxyguanosine at single-stranded DNA functionalized graphene modified glassy carbon electrode, Biosensors and Bioelectronics, 67 (2015) 139-145.

Highlights

1) Facile synthesis of Transition Metal Oxides based ZnO NFs@GOS nanocomposite have been developed.
2) The ZnO NFs@GOS was applied to the non-enzymatic biosensor of oxidative stress biomarker.
3) The nanocomposite is exhibits high selectivity and sensitivity.
4) The nanocomposite is exhibits nanomolar LOD.