Preparation and Characterizations of Graphene Oxide Screen Printing Electrodes

Manisha K. Borse[1], Vasant G. Wagh[2], Arun V. Patil[3]

[1-3]Department of Electronic Science and Research Centre, MGV's L.V.H Arts, Science and Commerce College, Panchavati, Nashik, Dist: Nashik, Maharashtra, India
[3]Department of Physics, MGV's, Arts, Science and Commerce College, Manmad, Dist. Nashik, Maharashtra, India.
Corresponding author-m1borse@gmail.com

Abstract:
Screen printing electrodes are now a days mostly used in many applications such as battery electrodes, biomedical, biosensors, boilermakers and other. In the present work, graphene oxide (GO)-based screen printing electrodes (SPEs) were successfully prepared on glass substrates using the screen printing technique and systematically characterized to evaluate their structural and morphological properties. Commercially available AR-grade GO nanopowder was utilized to prepare a thixotropic paste using ethyl cellulose (EC) and butyl carbitol acetate (BCA) in a 70:30 organic-to-inorganic ratio. The surface morphology studied by Scanning Electron Microscopy (SEM) revealed porous, wrinkled, and sheet-like structures of GO, providing a high surface area and interconnected pathways. Energy Dispersive X-ray (EDX) spectroscopy confirmed the presence of carbon (68.60 wt%, 74.43 at. %) and oxygen (31.40 wt. %, 25.57 at. %), indicating successful oxidation and functionalization of graphene. X-ray Diffraction (XRD) analysis showed a characteristic (001) diffraction peak at $2\theta \approx 11.1°$ (JCPDS No. 75-1621) with an interlayer spacing of 0.79 nm, while the crystallite size estimated using Scherrer's formula was found to be 12.55 nm. These results confirm the successful preparation of GO-based SPEs with desirable nanoscale features, making them promising candidates for electrochemical, sensing, and energy-related applications.

1. INTRODUCTION

Screen-printed electrodes (SPEs) have evolved into indispensable tools in modern electrochemical sensing, offering an affordable, robust, and versatile platform for miniaturized analysis. The origins of SPEs can be traced back several decades, rooted in the established thick-film technology used in electronics manufacture. By the early 1990s, researchers began recognizing their potential as electrochemical transducers for field-deployable applications [1]. Traditional electrochemical methods and electrodes such as glassy carbon or mercury-based systems were largely laboratory-bound, expensive, and required skilled handling. SPEs emerged as a disruptive alternative, delivering cost-effectiveness, disposability, and portability without sacrificing analytical performance [2, 3]. SPEs matured significantly through innovations in ink formulations and design. Early screen-printed carbon electrodes (SPCEs) were primarily plain carbon, but gradually the inks incorporated modifiers carbon nanotubes, graphene, gold or silver nanoparticles, conductive polymers, and more to tailor surface properties, widen electroactive areas, and enhance sensitivity and selectivity [3, 4]. In environmental sensing, SPEs have been adapted for rapid detection of pollutants, heavy metals (Pb^{2+}, Hg^{2+}), pesticides, and phenolic compounds, representing a practical instrument for in-situ monitoring of hazardous analytes [5, 6]. In pharmaceutical and biological analysis, SPE-based sensors have grown in popularity due to their single-use nature, low sample volume requirements, and minimal pretreatment demands. SPEs functionalized with enzymes, polymers, or nanocomposites have enabled rapid detection of drug molecules and biomarkers, making significant strides in healthcare diagnostics and drug testing [7, 8]. The modification of SPEs with shaped metallic nanoparticles (e.g., gold, silver) and carbon-based nanomaterials increases electroactive surface area and facilitates faster electron transfer, greatly improving analytical response and sensitivity [8, 9]. SPEs have been employed in flexible micro-supercapacitors using graphene inks, demonstrating impressive capacitance, mechanical robustness, and washability highlighting their applicability in wearable electronics and miniaturized energy storage [9].

Graphene oxide (GO) is a two-dimensional carbon nanomaterial derived from the chemical oxidation and exfoliation of graphite, and it possesses a unique combination of structural, chemical, and physical properties that distinguish it from pristine graphene. GO contains abundant oxygen-containing functional groups, including hydroxyl and epoxy groups on the basal plane as well as carbonyl and carboxyl groups at the sheet edges, which impart excellent hydrophilicity and allow stable dispersion in aqueous and polar solvents [10, 11]. These oxygen functionalities also provide versatile sites for chemical modification and functionalization, making GO a promising precursor for composites and hybrid materials [12]. GO exhibits a layered arrangement with an expanded interlayer spacing (~0.7–1.2 nm) compared to pristine graphite (0.34 nm), due to the presence of oxygen groups and intercalated water molecules [13]. GO is typically insulating or semiconducting, but partial reduction restores conductivity close to graphene, allowing tunability of electronic behavior [14]. GO exhibits a high surface area, good mechanical strength, and excellent flexibility, enabling its use in diverse applications such as sensors, supercapacitors, batteries, catalysis, membranes, and biomedical systems [15, 16]. Its processability in solution, combined with low-cost large-scale production, further enhances its technological importance across scientific and industrial domains.

Screen printing is a versatile, low-cost, and scalable fabrication technique that has gained increasing attention for the preparation of electrodes, sensors, and functional thin films. The process involves the transfer of a viscous ink or paste through a patterned mesh (stencil) onto a substrate, enabling controlled deposition of materials such as carbon, metal oxides, polymers, and nanomaterials [17, 18]. One of the key properties of screen printing is its ability to produce reproducible, uniform, and mechanically stable films with well-defined geometries. It offers compatibility with a wide range of substrates, including glass, ceramics, plastics, and flexible polymers, making it highly adaptable for diverse applications [18, 19]. The method is also characterized by its simplicity and high throughput, allowing large-scale manufacturing at relatively low temperatures compared to other thin-film deposition techniques. The screen printing provides excellent control over electrode thickness, surface morphology, and porosity by adjusting parameters such as paste viscosity, screen mesh size, and printing cycles. It facilitates the integration of nanomaterials such as graphene, carbon nanotubes, and metal nanoparticles into the inks, thereby improving the electrical, catalytic, and sensing properties of the electrodes [20, 21]. These features make screen printing an attractive method for producing electrodes in biomedical devices, electrochemical sensors, batteries, fuel cells, and flexible electronics [19-21].

The aim of the present work is to prepared graphene oxide based screen-printed electrodes on glass substrates using the screen-printing technique and to investigate the surface morphology, elemental composition, and crystallographic features of the prepared electrodes to validate their suitability for potential applications in electrochemical, sensing, and energy storage devices.

2. MATERIALS AND METHODS

The commercially available AR grade graphene oxide nanopowder was used for the preparation of screen printing electrodes. The SPEs of GO were prepared on clean glass substrates having dimension (breath 1 cm x length 3 cm). The all electrodes were initially clean with double distilled water and acetone to remove contaminations [22]. The 70:30 ratio of inorganic and organic materials was used for the preparation of screen printing electrodes. By using organic materials such as BCA and EC the thixotropic paste was formed and pasted on glass substrate by using screen printing setup as shown in Fig. 1. The SPEs were dried under IR lamp for 30 minutes and then annealed in the muffle furnace at 150 ^{o}C for 2 h. After that, SPEs are used for further characterizations [22, 23]. The prepared screen printing electrodes photos are shown in Fig. 2.

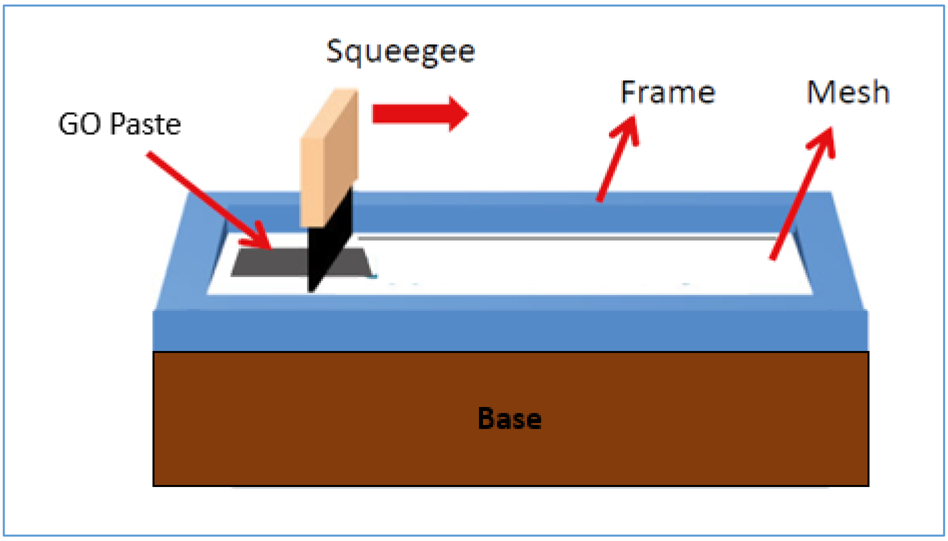

Fig. 1. Schematic diagram of screen printing set-up.

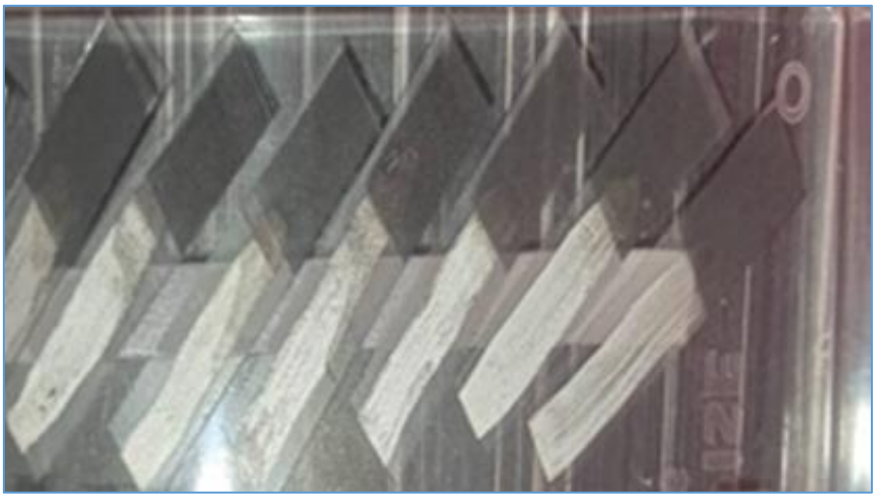

Fig. 2. Prepared screen printing electrodes

3. RESULT AND DISCUSSION

3.1 Scanning Electron Microscopy (SEM) Analysis

The surface morphology of the prepared graphene oxide screen printing electrodes was investigated using Scanning Electron Microscopy on a JEOL instrument operated at an accelerating voltage of 20 kV. The SEM micrographs at different magnifications are presented in Fig. 3 (a–d).

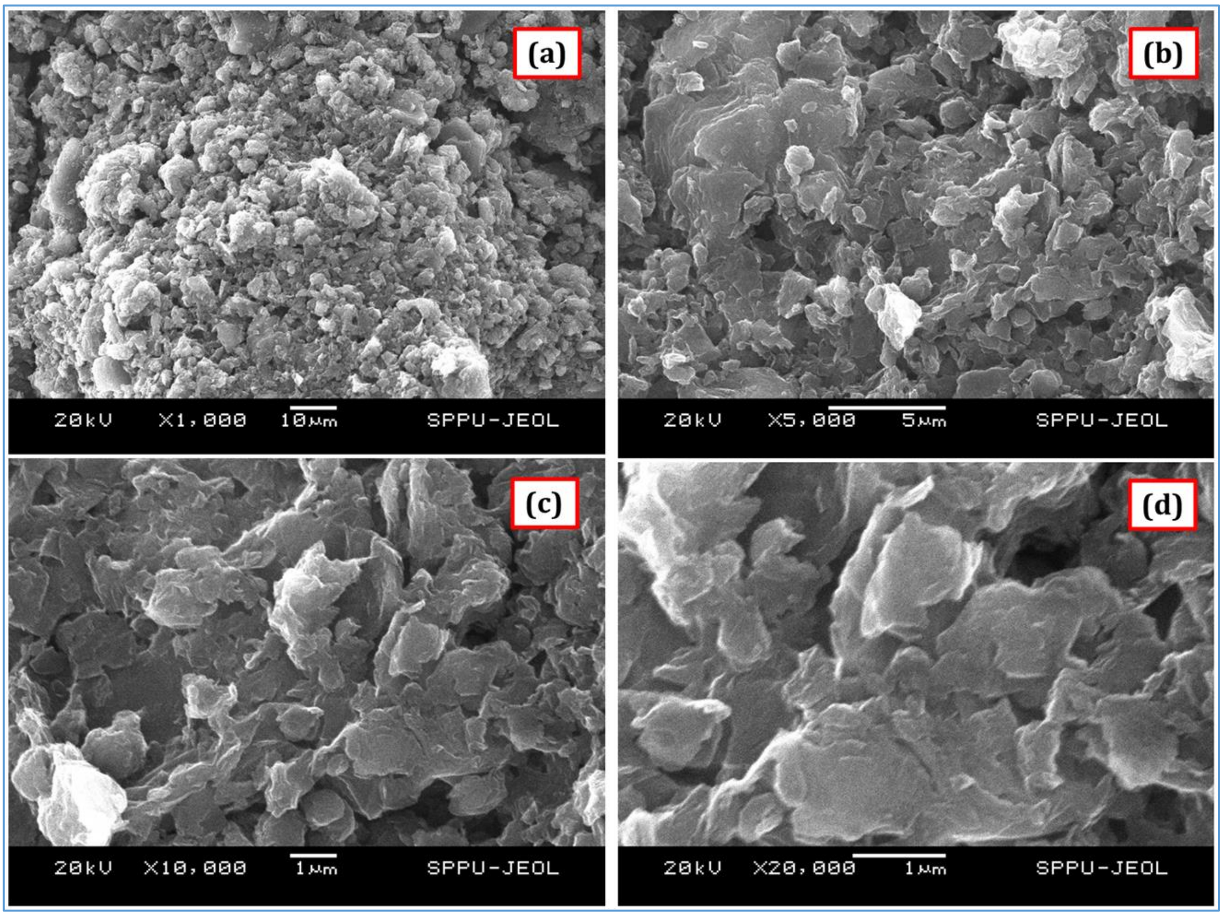

Fig. 3 (a-d). SEM micrographs of graphene oxide SPEs at different magnifications

At lower magnification (Fig. 3a, 1000×), the surface morphology reveals a highly porous and agglomerated structure, indicating the random distribution of GO flakes over the glass substrate. The porous nature of the electrode surface is beneficial as it enhances the surface-to-volume ratio, which is desirable for electrochemical and sensing applications [23, 24]. At higher magnification (Fig. 3b, 5000×), layered and sheet-like structures of GO become more prominent, confirming the successful deposition of graphene oxide in flake form. In Fig. 3c (10,000×), the overlapping of thin GO sheets is clearly visible, forming a wrinkled and crumpled morphology. This sheet-like arrangement contributes to good electrical conductivity and mechanical stability of the electrode. In Fig. 3d (20,000×), the GO nanosheets are observed, with distinct wrinkles and edges, which are characteristic features of graphene oxide morphology [25]. The presence of such wrinkled and interconnected nanosheets provides pathways for electron transport and offers a high density of active sites, making the prepared SPEs suitable for applications such as biosensing, catalysis, and energy storage [25-27]. The specific surface area was determined by Brunauer-Emmett-Teller method (Eq. 1) and it is found to be 2.68 m^2/ g.

$$Sw = 6/\rho d \quad \text{(Eq. 1)}$$

Where,
Sw is the specific surface area, d is the diameter of the particles and ρ is the composite density.

3.2 Energy-dispersive X-ray spectroscopy (EDX) Analysis

The EDX spectra of graphene oxide SPEs reveal in Fig. 4 shows two dominant signals corresponding to the C and O peaks observed at ≈0.3 keV and ≈0.5 keV, respectively, and the quantitative table yields C = 68.60 wt% (74.43 at%) and O = 31.40 wt% (25.57 at%).

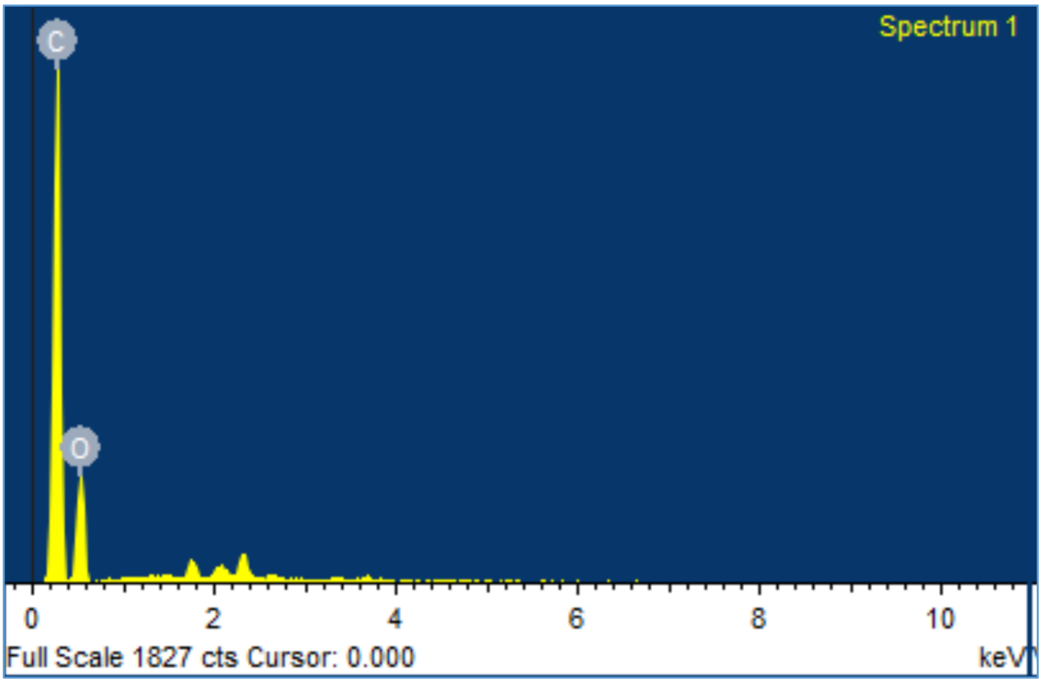

Fig. 4. EDX spectra of graphene oxide SPEs

These results confirm that the printed film is composed almost entirely of carbon and oxygen, consistent with graphene oxide [22, 26]. The atomic O/C ratio calculated from the atomic percentages is ~0.34 (25.57 / 74.43 ≈ 0.3436), indicating a moderate degree of oxidation in which a substantial fraction of the carbon network is functionalized with oxygen-containing group of hydroxyl which is characteristic of GO [25, 27].

X-ray diffraction (XRD) Analysis

The X-ray diffraction (XRD) pattern of the graphene oxide (GO) screen printing electrodes is shown in Fig. 5.

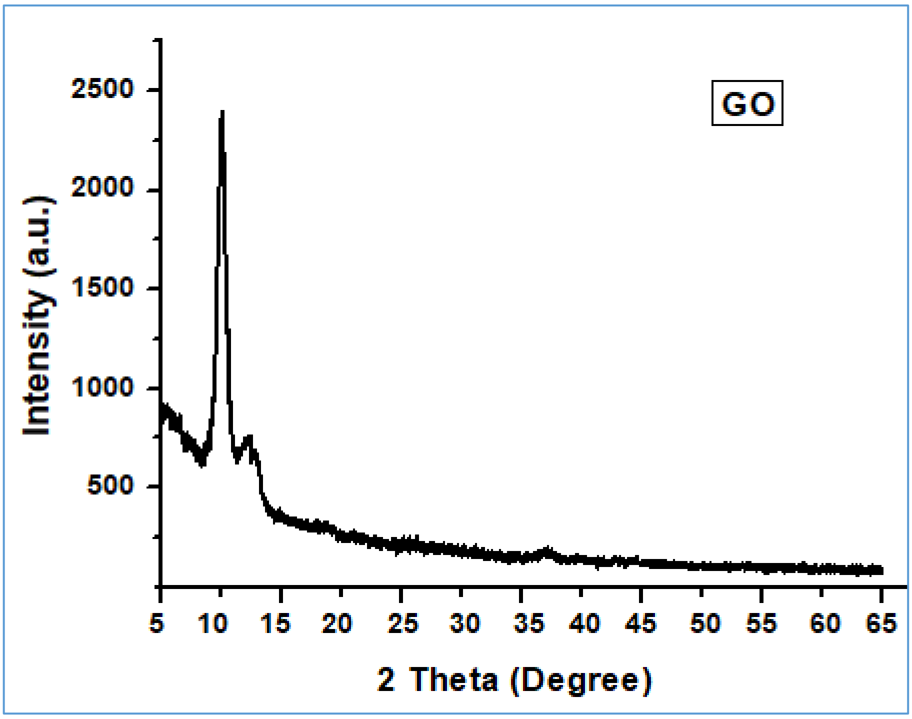

Fig. 5. XRD pattern of graphene oxide SPEs

A sharp and intense diffraction peak is observed at 2θ ≈ 11.1°, which corresponds to the (001) crystallographic plane of GO. This diffraction peak is a characteristic feature of graphene oxide. This confirms the insertion of oxygen-containing functional groups hydroxyl between the carbon layers, leading to an expanded layered structure. The obtained results are consistent with the standard JCPDS card data for graphene oxide (JCPDS No. 75-1621), which reports the (001) reflection in the range of 2θ [28, 29]. The crystallite size was estimated using Scherrer's formula (Eq. 2) and it is found to be 12.55 nm.

$$\text{Crystallite size } (D) = \frac{K\lambda}{\beta \, Cos\theta} \qquad \text{(Eq. 2)}$$

Where,
K-Constant (0.94), λ-wavelength (Cu-Kα-1.5404 A°), β-full-width at half maxima (FWHM), and θ-angle of diffraction.

The XRD analysis demonstrates that the prepared GO SPEs consist of highly oxidized graphene oxide with well-defined layered structures and expanded interlayer spacing [30, 31] which are favorable for applications in sensing and electrochemical devices due to improved ion diffusion and active surface area [31, 32].

CONCLUSIONS

The graphene oxide based screen printing electrodes were successfully prepared on glass substrates using the screen printing technique and characterized by SEM, EDX, and XRD analyses. SEM micrographs revealed a porous, wrinkled, and sheet-like morphology of GO flakes, which enhances the surface-to-volume ratio and provides abundant active sites for electrochemical interactions. EDX analysis confirmed the elemental composition of the electrodes with dominant carbon and oxygen peaks, consistent with the presence of oxygenated functional groups in GO. The XRD results showed a characteristic diffraction peak at ~11.1° corresponding to the (001) plane of GO (JCPDS No. 75-1621) confirming successful oxidation and exfoliation. These findings collectively validate the successful preparation of GO-based SPEs with desirable structural and morphological features, making them promising candidates for sensing and energy-related applications.

Declaration of competing interest

The authors declare that they have no known competing financial interest.

Acknowledgment

The authors also would like to thank to Principal, MGV's Loknete Vyankatrao Hiray Arts, Science and Commerce College Panchavati, Nashik (India) for providing necessary research lab facilities. Authors also thankful acknowledge Department of Physics and CIF, Savitribai Phule Pune University, Pune for providing SEM, EDX and XRD characterizations facilities.

REFERENCES:

1. Hughes, G., Pemberton, R. M., Hart, J. P., & Honeychurch, K. C. (2016). Recent advances in the fabrication and application of screen-printed electrochemical (bio)sensors based on carbon materials for biomedical, agri-food and environmental analyses. *Biosensors*, 6(4), 50.
2. Honeychurch, K. C. (2015). Recent developments, characteristics and potential applications of screen-printed electrodes in pharmaceutical and biological analysis. *TrAC Trends in Analytical Chemistry*, 76, 264–279.
3. González-Sánchez, M. I., Foster, C. W., & Banks, C. E. (2021). Recent trends in the improvement of the electrochemical response of screen-printed electrodes by their modification with shaped metal nanoparticles. *Sensors*, 21(8), 2596.
4. Suresh, R. R., Lakshmanakumar, M., Arockia Jayalatha, J. B. B., Rajan, K. S., Sethuraman, S., Krishnan, U. M., & Rayappan, J. B. B. (2021). Fabrication of screen-printed electrodes: opportunities and challenges. Journal of Materials Science, 56(15), 8951-9006.
5. Foster, C. W., Down, M. P., Zhang, Y., Ji, X., Rowley-Neale, S. J., Smith, G. C., & Banks, C. E. (2021). Screen-printed electrodes: Transitioning the laboratory into the field. *Talanta Open*, 3, 100032.
6. Honeychurch, K. C. (2019). Applications of chemically modified screen-printed electrodes in food analysis and quality monitoring: A review. *Foods*, 8(12), 640.
7. Electronic Specifier. (2025). Screen-printed electrodes for biosensors are revolutionising point-of-care applications. Retrieved from https://www.electronicspecifier.com

8. Specialist Printing Worldwide. (2025). Screen-printed electrodes – revolutionising point-of-care applications. Retrieved from https://aws.specialistprinting.com
9. Bellani, S., Petroni, E., Del Rio Castillo, A. E., Curreli, N., Martín-García, B., Oropesa-Nuñez, R., Prato, M., & Bonaccorso, F. (2019). Scalable production of graphene inks via wet-jet milling exfoliation for screen-printed micro-supercapacitors.
10. Dreyer, D. R., Park, S., Bielawski, C. W., & Ruoff, R. S. (2010). *The chemistry of graphene oxide*. Chemical Society Reviews, 39(1), 228–240.
11. Lerf, A., He, H., Forster, M., & Klinowski, J. (1998). *Structure of graphite oxide revisited*. Journal of Physical Chemistry B, 102(23), 4477–4482.
12. Pei, S., & Cheng, H. M. (2012). *The reduction of graphene oxide*. Carbon, 50(9), 3210–3228.
13. Stankovich, S., Dikin, D. A., Dommett, G. H., et al. (2006). *Graphene-based composite materials*. Nature, 442, 282–286.
14. Eda, G., & Chhowalla, M. (2010). *Chemically derived graphene oxide: Towards large-area thin-film electronics and optoelectronics*. Advanced Materials, 22(22), 2392–2415.
15. Singh, V., Joung, D., Zhai, L., Das, S., Khondaker, S. I., & Seal, S. (2011). *Graphene based materials: Past, present and future*. Progress in Materials Science, 56(8), 1178–1271.
16. Compton, O. C., & Nguyen, S. T. (2010). *Graphene oxide, highly reduced graphene oxide, and graphene: versatile building blocks for carbon-based materials*. Small, 6(6), 711–723.
17. Hughes, G., Pemberton, R. M., Hart, J. P., & Honeychurch, K. C. (2016). Recent advances in the fabrication and application of screen-printed electrochemical (bio)sensors based on carbon materials for biomedical, agri-food and environmental analyses. *Biosensors*, 6(4), 50.
18. Honeychurch, K. C. (2015). Recent developments, characteristics and potential applications of screen-printed electrodes in pharmaceutical and biological analysis. *TrAC Trends in Analytical Chemistry*, 76, 264–279.
19. Foster, C. W., Down, M. P., Zhang, Y., Ji, X., Rowley-Neale, S. J., Smith, G. C., & Banks, C. E. (2021). Screen-printed electrodes: Transitioning the laboratory into the field. *Talanta Open*, 3, 100032.
20. González-Sánchez, M. I., Foster, C. W., & Banks, C. E. (2021). Recent trends in the improvement of the electrochemical response of screen-printed electrodes by their modification with shaped metal nanoparticles. *Sensors*, 21(8), 2596.
21. Honeychurch, K. C. (2019). Applications of chemically modified screen-printed electrodes in food analysis and quality monitoring: A review. *Foods*, 8(12), 640.
22. Patil, A. B., Tupe, U. J., Halwar, D. K., Deshmane, V. V., & Patil, A. V. (2023). Investigation of structural and optical properties of graphene derivatives as a route for optical sensing. Materials Today: Proceedings, 73, 418-426.
23. Mandawade, S. S., Wagh, R. V., Yewale, C. R., Qadir, K. W., Abdullah, H. Y., Alharbi, T., ... & Patil, A. V. (2025). Graphene oxide nanoparticles synthesized via hummers method and investigation of structural, electrical, and gas-sensing properties of screen-printed thick films. *Journal of the Indian Chemical Society*, *102*(1), 101514.
24. Patil, A. B., Tupe, U. J., Deshmane, V. V., Halwar, D. K., Patil, S. J., & Patil, A. V. Potentiometric Study and Statistical Analysis of Human Urine Samples using Reduced Graphene Oxide Screen Printed Electrodes.
25. Su, P., Wang, F., Li, Z., Tang, C. Y., & Li, W. (2020). Graphene oxide membranes: controlling their transport pathways. *Journal of Materials Chemistry A*, *8*(31), 15319-15340.
26. Zou, F., Zhou, H., Jeong, D. Y., Kwon, J., Eom, S. U., Park, T. J., ... & Lee, J. (2017). Wrinkled surface-mediated antibacterial activity of graphene oxide nanosheets. *ACS applied materials & interfaces*, *9*(2), 1343-1351.
27. Kang, Y., Qiu, R., Jian, M., Wang, P., Xia, Y., Motevalli, B., ... & Zhang, X. (2020). The role of nanowrinkles in mass transport across graphene-based membranes. *Advanced Functional Materials*, *30*(32), 2003159.
28. Avar, B., & Panigrahi, M. (2022). Synthesis and characterization of binary reduced graphene oxide/metal oxide nanocomposites. *Physics and Chemistry of Solid State*, *23*(1), 101-112.

29. Sarma, S., & Chandra Ray, S. (2021). Low Temperature ferromagnetic behavior of graphene oxide (GO) and molybdenum disulphide (MoS2) hybrid nanocomposite. *Journal of Nanoscience and Nanotechnology*, *21*(6), 3320-3324.
30. Chen, D., Feng, H., & Li, J. (2012). Graphene oxide: preparation, functionalization, and electrochemical applications. *Chemical reviews*, *112*(11), 6027-6053.
31. Xu, J., Wang, Y., & Hu, S. (2017). Nanocomposites of graphene and graphene oxides: synthesis, molecular functionalization and application in electrochemical sensors and biosensors. A review. *Microchimica Acta*, *184*(1), 1-44.
32. Sajjad, S., Khan Leghari, S. A., & Iqbal, A. (2017). Study of graphene oxide structural features for catalytic, antibacterial, gas sensing, and metals decontamination environmental applications. *ACS Applied Materials & Interfaces*, *9*(50), 43393-43414.