International Research Journal of Management Science & Technology

ISSN 2250 – 1959(0nline)
2348 – 9367 (Print)

An Internationally Indexed Peer Reviewed & Refereed Journal

www.IRJMST.com
www.isarasolutions.com

Published by iSaRa Solutions

"PVA-PPy-AgNP-GO Nanocomposites for Chemical and Biological Sensors: A Review."

[1]Abhishek Padwal, [1]Gitesh Padhye, [2]Abhishek Gavade, [2]Priyalatha Alexander, [2]Sushma Pimpale

[1]Thakur College of Science and Commerce, Kandivali East, Mumbai, India

[2]Patkar-Varde College, Goregaon West, Mumbai, India

Abstract

In recent years, composite nanomaterials comprising polyvinyl alcohol (PVA), polypyrrole (PPy), silver nanoparticles (AgNPs), and graphene oxide (GO) have got significant attention due to their exceptional mechanical flexibility, electrical properties, and surface characteristics, these materials hold great promise as functional layers for high-performance sensors. This paper reviews the latest advancements in the preparation and characterization of such composite systems, with a particular focus on how material composition, filler morphology, and fabrication processes influence charge transport and sensor performance and applications of these materials in gas/vapor, chemical, electrochemical, and strain sensing, showcasing key performance parameters such as sensitivity, stability, etc. Special emphasis is placed on the synergistic effects demonstrated by polypyrrole, silver nanoparticles, and graphene oxide in constructing conductive networks and providing abundant functional sites necessary for interacting with target analytes. In summary, the current challenges facing this field such as the influence of humidity, long-term stability, and reproducibility in large-scale applications and outlines the promising prospects for developing scalable, wearable, and multifunctional sensing platforms based on PVA-PPy-AgNP-GO nanocomposites.

Keywords: Polypyrrole, Graphene Oxide, Silver Nanoparticles, Nanocomposites.

1 Introduction

Polymer-based nanocomposites are expanding in their applications within the field of sensing, owing to the ability to combine mechanical flexibility, easy to process, and tunable electrical properties. In particular, electrically conductive polymeric materials specifically those doped with metallic or carbon-based nanostructures holds significant promise for applications requiring highly sensitive and low-power detection of gases, chemicals, and biomolecules.[1], [2], [3] Although polyvinyl alcohol (PVA) possesses excellent film-forming properties, it is inherently insulating nature which imposes limitations on its direct use in electronic sensing devices. However, by incorporating polypyrrole (PPy), silver nanoparticles (AgNPs), & graphene oxide (GO) into a PVA matrix, it becomes possible to establish electrically conductive pathways. As a result, PVA-PPy-AgNP-GO nanocomposites are getting significant attention as having a versatile class of sensing materials, suitable for use in flexible resistive sensors, electrochemical sensors.[4], [5] simultaneously enhance the flexibility and strength of the resulting film. This produces a composite material that is particularly well suited for use in flexible sensors.[9], [10], [11], [12] Semiconducting channels within polymer nanocomposites, thereby facilitating charge transport. For these reasons, GO is widely employed as a reinforcing agent and filler in polymer-based sensors. In this context, it provides numerous active sites that

enhance the adsorption of target analytes, thereby increasing the sensitivity of the sensors.[17], [18], [19]

2 Synergistic effects in PVA - PPy - AgNP - GO nanocomposites

By integrating these various polymers and materials into a single nanocomposite, each component contributes significantly to the sensor's overall performance. The PVA polymer acts as a host matrix, providing flexibility, processability, and in many cases biocompatibility; at the same time, the PPy polymer creates an internal conductive framework within this matrix. [20] Furthermore, the functionality of silver nanoparticles (AgNPs) extends beyond just conductive enhancement; they also contribute to signal amplification through catalytic and plasmonic effects. At the same time, graphene oxide (GO) forms extensive networks that provide both conductive and mechanical reinforcement, facilitated by strong interfacial interactions with both PVA and PPy.[7], [21] The resulting multi-component system is capable of forming interconnected conductive pathways characterized by a high density of electrochemically active sites and adsorption sites, a property that proves to be very useful for the purposes of resistivity and electrochemical sensing of gases, chemical analytes, and biomolecules [21]

3 Synthesis and fabrication of PVA - PPy - AgNP - GO nanocomposites

3.1 Preparation of individual components

PVA solutions are typically prepared by mixing the polymer powder in deionized water at elevated temperature (about 70–90 °C) under stirring till a clear, viscous solution is obtained.[22] Silver nanoparticles are most often synthesized by wet-chemical reduction of silver salts, for example the citrate-reduction (Turkevich) method, or generated in situ within PVA by chemical or electrochemical routes.[22] By modified Hummers, Graphene oxide is commonly produced, followed by exfoliation in water to give stable GO dispersions.[23] PPy is generally obtained by oxidative polymerization of pyrrole using oxidants such as ferric chloride or persulfates in aqueous or mixed solvents.[2]

3.2 In-situ oxidative polymerization in PVA/AgNP/GO media

Chemical oxidation polymerization is one which widely used in the production of PVA-PPy-AgNP-GO nanocomposites. Mix the liquid and AgNP colloid solution and stir (in most cases under cooling) to disperse the filler evenly. O directly starts the production of PPy inside the medium. The reaction mixture gradually turns black, and by continuing to stir for some time, the PPy chain extends around the GO sheet and AgNP. This promotes strong contact at the interface and forms an interconnected conductive network. By adjusting the concentration of monomer, oxidizing agent, and filler, it is possible to control the relative content and form of PPy, AgNP, and GO in the final nanocomposite film.[2], [18], [22], [24], [25]

3.3 Alternative mixing and assembly strategies

In addition to all in-situ synthesis methods, ex-situ methods are also used, where pre-synthesized PPy, AgNPs, and GO are mixed with a PVA solution, which is then poured or coated. Some studies adopt a technique in which polypyrrole is first prepared on graphene oxide or other support materials; this hybrid material is then dispersed within a polyvinyl alcohol matrix. This method facilitates good dispersion and enables structural control over the filler materials. In addition, methods involving the electrospinning of PVA-based mixtures to form nanofibers - followed by the in-situ polymerization of pyrrole directly onto them - have been explored; this technique produces sensing layers characterized by high porosity and large surface areas. In addition, other used methods include electrochemical deposition of PPy on substrates modified with PVA or GO, as well as

techniques using GO as an oxidizing agent and graphene precursor to create composite graphene-PPy structures, which are subsequently mixed with PVA and AgNPs.[3], [22]

3.4 Film formation and device fabrication

In optical applications, nanocomposite films are usually deposited on rigid or flexible substrates such as glass, polyethylene terephthalate, or metal electrodes using techniques such as solution casting, drop casting, spin coating, etc. Film thickness is determined by factors such as solution concentration, casting volume, and withdrawal or spinning parameters; typically, the thickness of the coatings ranges from 10 to several hundred of micrometres, but the thickness of the coatings applied directly on the electrodes is less than one micrometre. To enhance film uniformity, adhesion, and conductivity, post-treatments, such as drying under elevated temperatures, gentle thermal annealing, or partial chemical reduction can be used. Subsequently, interdigitated electrodes, screen-printed conductors, or patterned metal contacts are combined with the nanocomposite layer to create resistive or electrochemical sensors.[2]

4 Sensor mechanisms and configurations

4.1 Chemiresistive sensing mechanism

In chemiresistive sensors, a thin film composed of PVA, PPy, AgNPs, and GO acts as a variable resistor, the resistance value of which changes as target analyte molecules interact with the sensor surface. The adsorption of gases or vapours onto PPy, GO, and AgNP sites induces charge transfer or modulates the carrier density within the conductive network; this effect manifests as an increase or decrease in the film's resistance value.[26], [27], [28] The incorporation of AgNPs and GO nanosheets enhances the sensor's chemiresistive response performance by providing additional adsorption sites, promoting interfacial polarization, and accelerating electron transport through percolation pathways.[24], [29], [30], [31]

4.2 Electrochemical sensing mechanism

In electrochemical sensors, nanomaterial composites are typically coated onto conductive substrates, such as glassy carbon electrodes, indium tin oxide electrodes, or screen-printed electrodes. In this configuration, the PVA-PPy-AgNP-GO layer functions as an energy transducer, facilitating transfer of electron between the electrochemically active analyte in solution and the working electrode. PPy provides a conductive matrix for redox reactions, while AgNP particles possess high conductivity and typically serve as electrochemically active sites. GO or reduced GO offers a large surface area and promotes the dispersion of catalytic nanoparticles. During measurements, the analyte undergoes oxidation or reduction at the active sites, generating a current signal whose magnitude corresponds to its concentration, thereby enabling quantitative detection.[14], [32], [33]

5 Applications of PVA - PPy - AgNP - GO sensors

At room temperature, PVA-PPy-AgNP-GO nanocomposites demonstrate significant potential for sensing gases and vapours. The fact that PPy/GO network provides chemical stability, while the AgNP nanoparticles enhance conductivity and surface reactivity. Similar PPy/graphene and PPy/Ag systems have exhibited high sensitivity to ammonia and other volatile analytes, as their porous structure combined with strong analyte adsorption onto the conductive network enables rapid response and recovery. Incorporating graphene oxide in the PVA-PPy-AgNP matrix increases the available surface area introduce additional pathways for charge transport. This proves advantageous for detecting low concentrations of reducing or oxidizing gases in applications such as air quality monitoring and breath analysis.[34], [35], [36], [37] In electrochemical systems, PVA-PPy-AgNP-GO films deposited on conductive electrodes are used to detect small molecules like hydrogen

peroxide, nitrite, and other redox-active substances. Studies involving PPy-AgNP-GO nanofiber composites have demonstrated that, owing to the catalytic activity of the AgNP molecules and graphene oxide as it has the large surface area, these materials exhibit high efficiency in H_2O_2 sensing. Similar GO/PPy layered structures have also been employed for the high-sensitivity detection of 4-aminophenol and other organic pollutants, thereby demonstrating that PVA based hybrid materials serve as effective platforms for the environmental monitoring of water and industrial wastewater.[31], [35], [36], [38]. The hydrophilic PVA matrix, together with the functional groups on GO and the conductive PPy/AgNP network, provides a suitable interface for immobilizing biomolecules such as enzymes, antibodies, and nucleic acids. Graphene-oxide/PPy electrodes have been used to construct biosensors for analytes like bilirubin, where GO nanoparticles decorated with PPy support enzyme attachment and efficient electron transfer. Introducing PVA into such systems can improve film processability and biocompatibility, making PVA-PPy-AgNP-GO nanocomposites promising candidates for point-of-care diagnostic sensors and wearable biochemical monitoring devices.[39], [40], [41], [42]

6 Factors influencing sensor performance

6.1 Composition and filler loading

The sensor's performance is largly determined by the proportions of polypyrrole, silver nanoparticles, and graphene oxide present within a polyvinyl alcohol matrix. Conductive polymer-based nanocomposites typically exhibit an optimal loading range for nanofillers a window in which a conductive, percolating network can be established without excessive agglomeration. An insufficient filler content leads to reduced conductivity and a diminished response, whereas an excessive loading of silver nanoparticles or graphene oxide results in particle agglomeration, increased noise, and heightened mechanical brittleness. In systems loaded with graphene or reduced graphene oxide (rGO) as is the case with other gas sensors an excessive loading of carbon fillers generally yields high conductivity but a low response; consequently, a moderate filler content typically strikes the optimal balance between sensitivity and baseline resistance.[7], [43]

6.2 Morphology, dispersion, and interfacial structure

The distribution of silver nanoparticles and graphene oxide sheets, as well as the nature of the interactions between polypyrrole and polyvinyl alcohol significantly influence charge transport pathways. Small, evenly dispersed metal nanoparticles, combined with well-exfoliated graphene oxide can improve sensitivity by increasing the active surface area as well as contact area with the conductive polymer network. Conversely, poor dispersion or excessive aggregation reduces the active surface area, leading to the formation of localized current pathways that limit reproducibility and stability. Interfacial interactions such as hydrogen bonding between polyvinyl alcohol and graphene oxide, or π-π interactions and charge transfer between polypyrrole and graphene oxide contribute to efficient charge transport and robust mechanical bonding; this is of critical importance for flexible materials and stress-sensing applications.[7], [44]

6.3 Intrinsic properties of AgNPs and GO

The size and chemical structure on silver nanoparticles (AgNPs) influence their properties and detection performance. Smaller silver nanoparticles exhibit stronger SPR (surface plasmon resonance) and redox effects, which enhance the signal change when the analyte interacts with them. However, these nanoparticles are prone to oxidation and dissolution, which may affect their long-term stability. Furthermore, the redox potential of graphene oxide determines the permeability and yield of functional groups. Low molecular weight graphene oxide achieves an excellent balance

between generating conduction paths and providing multiple adsorption sites, two properties that are difficult to reconcile, enabling applications in electrochemical and gas sensing.[45]

6.4 Environmental conditions

Conductive nanocomposite polymer sensors exhibit dependence on high and ambient temperatures. The hydrophilic polyvinyl alcohol (PVA) matrix can absorb moisture, thereby altering the membrane's porosity, dielectric properties, and ionic conductivity, which in turn affects analyte retention and reaction at the interface. Temperature affects carrier mobility and adsorption kinetics, thus altering sensitivity, reaction/recovery time, and detection limit. Interacting gases or related compounds compete with polypyrrole (PPy), graphene oxide (GO), and silver nanoparticles (AgNPs) for adsorption sites; therefore, material selection is closely related to performance, surface modification, and the use of filters or recognition layers.[46]

7 Challenges

PVA-PPy-AgNP-GO sensors suffer from several challenges in terms of both materials and applications. Longevity is a major concern because PPy can undergo excessive oxidation, structural relaxation, and changes in doping levels, leading to changes in core resistance and decreased sensitivity over time. The hydrophilic PVA matrix reacts strongly to humidity, complicating sample interpretation due to humidity degradation and proton transfer, which can reduce selectivity in gas and chemical sensing. The homogeneous dispersion of AgNP and GO molecules under high loads is difficult, and aggregation can reduce mechanical flexibility, increase noise, and cause inter-functional variations. Other concerns include the potential release and cytotoxicity of silver ions in biosensing and sensing devices, the difficulty of scaling up the large-scale membrane, recyclability, and robust design for environmentally friendly and coordination with electronic devices.[47], [48], [49]

8 Future directions

Future research on PVA-Ppy-AgNP-GO sensors is likely to focus on enhancing their stability and selectivity, as well as integrating them into practical systems. Strategies such as encapsulation within breathable barrier layers, the incorporation of more stable enhancing agents, or the utilization of conductive hydrogels or cross-linked PVA networks prove effective in mitigating the effects of heat and degradation over time while preserving flexibility. Furthermore, molecular imprinting techniques, the incorporation of biorecognition elements, and targeted surface functionalization of GO and AgNPs represent effective strategies for enhancing selectivity toward specific gases, ions, or biomarkers. Combining optimization based on structural and microstructural data with printing and coating techniques will enable the development of scalable manufacturing systems for current sensor arrays, imaging modalities, and conformal devices.[31], [46], [47], [50]

9 Conclusion

The PVA-PPy-AgNP-GO nanocomposite combines a flexible, functional polymer matrix with a multifunctional, highly conductive hybrid filler network, making it ideally suited for gas, chemical, biological, and voltage sensing applications. The synergistic combination of PPy, AgNP, and GO facilitates enhanced charge transport, provides multiple active sites, and enables tunable sensing mechanisms all of which can be modulated through synthetic conditions, filler ratios, and device architecture. However, challenges regarding stability, temperature response, large-area compatibility, and safety continue to hinder the transition of these materials from laboratory experiments to commercial products. By addressing these challenges through advanced material design, device functionalization, and system-level integration, it is anticipated that the full potential of PVA-PPy-

AgNP-GO nanocomposites in sensing technologies including their scalability for large-scale applications can be fully realized.[40], [51]

References

[1] D. M. Nerkar, S. E. Jaware, and G. G. Padhye, "Fabrication of a Novel Flexible Room Temperature Hydrogen Sulfide (H 2 S) Gas Sensor based on Polypyrrole Films," 2013. [Online]. Available: www.ijsr.net

[2] D. M. Nerkar, S. V Panse, S. P. Patil, S. E. Jaware, and G. G. Padhye, "Sensors & Transducers Polypyrrole-silver Nanocomposite: Synthesis and Characterization," 2016. [Online]. Available: http://www.sensorsportal.com

[3] D. M. Nerkar, "Selective and Sensitive Room Temperature Detection of Ammonia by PPy-Ag Nanocomposite," *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. 6, no. 3, pp. 1241–1249, Mar. 2018, doi: 10.22214/ijraset.2018.3194.

[4] G. Kaladevi, S. Meenakshi, K. Pandian, and P. Wilson, "Synthesis of Well-Dispersed Silver Nanoparticles on Polypyrrole/Reduced Graphene Oxide Nanocomposite for Simultaneous Detection of Toxic Hydrazine and Nitrite in Water Sources," *J. Electrochem. Soc.*, vol. 164, no. 13, pp. B620–B631, 2017, doi: 10.1149/2.0611713jes.

[5] P. Moozarm Nia, F. Lorestani, W. P. Meng, and Y. Alias, "A novel non-enzymatic H2O2 sensor based on polypyrrole nanofibers-silver nanoparticles decorated reduced graphene oxide nano composites," *Appl. Surf. Sci.*, vol. 332, pp. 648–656, Mar. 2015, doi: 10.1016/j.apsusc.2015.01.189.

[6] S. Gahlot, V. Kulshrestha, G. Agarwal, and P. K. Jha, "Synthesis and characterization of PVA/GO nanocomposite films," in *Macromolecular Symposia*, Wiley-VCH Verlag, Nov. 2015, pp. 173–177. doi: 10.1002/masy.201400220.

[7] K. M. Abu Hurayra–Lizu, M. W. Bari, F. Gulshan, and M. R. Islam, "GO based PVA nanocomposites: tailoring of optical and structural properties of PVA with low percentage of GO nanofillers," *Heliyon*, vol. 7, no. 5, May 2021, doi: 10.1016/j.heliyon.2021.e06983.

[8] A. M. S. Alhuthali, H. Kalil, and M. A. Ibrahim, "Evaluating the reactivity of polyvinyl alcohol/graphene nanocomposites," *Opt. Mater. (Amst).*, vol. 151, May 2024, doi: 10.1016/j.optmat.2024.115364.

[9] W. S. Barde and S. S. Arsad, "Effect of Concentration Of FeCl 3 on Ionic Conductivity of Polypyrrole-Poly (Vinyl Acetate) Composite." [Online]. Available: www.ijert.org

[10] Z. Shu, C. Yi, C. Yin, X. Zhang, and C. Peng, "A Polyvinyl Alcohol Hydrogel Based on a Polypyrrole/Biomass Carbon Nanosphere Synergistic Network for Flexible Pressure Sensors," *Gels*, vol. 11, no. 12, p. 956, Nov. 2025, doi: 10.3390/gels11120956.

[11] A. Kassim, Z. Bte Basar, and H. N. M Ekramul Mahmud, "Effects of preparation temperature on the conductivity of polypyrrole conducting polymer," 2002.

[12] N. V. Dave and D. M. Nerkar, "The influence of the oxidant on structural and morphological properties of conductive polypyrrole," in *Materials Today: Proceedings*, Elsevier Ltd, 2020, pp. 5939–5943. doi: 10.1016/j.matpr.2020.09.104.

[13] Y. Dou, J. Peng, W. Li, M. Li, H. Liu, and H. Zhang, "Effects of reducibility of graphene oxide nanosheets on preparation of AgNPs/GO nanocomposites and their electrocatalytic performance," *Journal of Nanoparticle Research*, vol. 17, no. 12, pp. 1–10, Dec. 2015, doi: 10.1007/s11051-015-3300-2.

[14] Q. Zhao, M. Zhao, J. Qiu, W. Y. Lai, H. Pang, and W. Huang, "One Dimensional Silver-based Nanomaterials: Preparations and Electrochemical Applications," Oct. 11, 2017, *Wiley-VCH Verlag*. doi: 10.1002/smll.201701091.

[15] G. Sabarees, V. Velmurugan, G. P. Tamilarasi, V. Alagarsamy, and V. Raja Solomon, "Recent Advances in Silver Nanoparticles Containing Nanofibers for Chronic Wound Management," Oct. 01, 2022, *MDPI*. doi: 10.3390/polym14193994.

[16] M. Boyrazli, M. Yalcin, A. Dere, and F. Yakuphanoglu, "Electrical and dielectric behavior of PVA nanocomposites doped with graphene oxide: Effects of doping level and frequency," *J. Alloys Compd.*, vol. 1031, p. 180916, Jun. 2025, doi: 10.1016/J.JALLCOM.2025.180916.

[17] Y. Zhu, D. K. James, and J. M. Tour, "New routes to graphene, graphene oxide and their related applications," Sep. 18, 2012. doi: 10.1002/adma.201202321.

[18] S. Hazra and S. Basu, "Graphene-Oxide Nano Composites for Chemical Sensor Applications," *C (Basel).*, vol. 2, no. 2, p. 12, Apr. 2016, doi: 10.3390/c2020012.

[19] P. Poulin *et al.*, "Superflexibility of graphene oxide," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 113, no. 40, pp. 11088–11093, Oct. 2016, doi: 10.1073/pnas.1605121113.

[20] Miss. N. V. Dave, "Effect of Molar Ratio on Structure of PPy-PVA Composite Film," *International Journal of Current Science Research and Review*, vol. 05, no. 03, Mar. 2022, doi: 10.47191/ijcsrr/V5-i3-19.

[21] W. S. B. Dwandaru, A. Fathia, and R. I. Wisnuwjaya, "Study on the Synthesis of GO-AgNP Mixture Assisted by AgNP Based on UV-Vis, SEM-EDX, XRD, and FTIR," in *Journal of Physics: Conference Series*, Institute of Physics Publishing, Oct. 2018. doi: 10.1088/1742-6596/1097/1/012011.

[22] D. Nerkar, M. Rajwade, S. Jaware1, and M. Jog, "Synthesis and characterization of Polyvinyl Alcohol-Polypyrrole-Silver nanocomposite polymer films with core-shell structure," 2020. [Online]. Available: http://creativecommons.org/licenses/by/4.0/.

[23] M. M. Rahman *et al.*, "Synthesis of polyaniline-graphene oxide based ternary nanocomposite for supercapacitor application," *J. Energy Storage*, vol. 67, Sep. 2023, doi: 10.1016/j.est.2023.107615.

[24] H. Y. Mohammed *et al.*, "Selective and sensitive chemiresistive sensors based on polyaniline/graphene oxide nanocomposite: A cost-effective approach," *Journal of Science: Advanced Materials and Devices*, vol. 7, no. 1, Mar. 2022, doi: 10.1016/j.jsamd.2021.08.004.

[25] D. A. Dikin *et al.*, "Preparation and characterization of graphene oxide paper," *Nature*, vol. 448, no. 7152, pp. 457–460, Jul. 2007, doi: 10.1038/nature06016.

[26] P. Recum and T. Hirsch, "Graphene-based chemiresistive gas sensors," Oct. 23, 2023, *Royal Society of Chemistry*. doi: 10.1039/d3na00423f.

[27] F. L. Meng, Z. Guo, and X. J. Huang, "Graphene-based hybrids for chemiresistive gas sensors," May 01, 2015, *Elsevier B.V.* doi: 10.1016/j.trac.2015.02.008.

[28] S. M. Majhi, A. Mirzaei, H. W. Kim, S. S. Kim, and T. W. Kim, "Recent advances in energy-saving chemiresistive gas sensors: A review," Jan. 01, 2021, *Elsevier Ltd*. doi: 10.1016/j.nanoen.2020.105369.

[29] A. G. Bannov, J. Prášek, O. Jašek, and L. Zajíčková, "Investigation of pristine graphite oxide as room-temperature chemiresistive ammonia gas sensing material," *Sensors (Switzerland)*, vol. 17, no. 2, Feb. 2017, doi: 10.3390/s17020320.

[30] R. Kumar and A. Kaur, "Chemiresistive gas sensors based on thermally reduced graphene oxide for sensing sulphur dioxide at room temperature," *Diam. Relat. Mater.*, vol. 109, Nov. 2020, doi: 10.1016/j.diamond.2020.108039.

[31] R. Kumar, D. K. Avasthi, and A. Kaur, "Fabrication of chemiresistive gas sensors based on multistep reduced graphene oxide for low parts per million monitoring of sulfur dioxide at room temperature," *Sens. Actuators B Chem.*, vol. 242, pp. 461–468, Apr. 2017, doi: 10.1016/j.snb.2016.11.018.

[32] D. Chen, H. Feng, and J. Li, "Graphene oxide: Preparation, functionalization, and electrochemical applications," Nov. 14, 2012. doi: 10.1021/cr300115g.

[33] M. M. Abudabbus, "UNIVERSITY OF BELGRADE FACULTY OF TECHNOLOGY AND METALLURGY ELECTROCHEMICAL SYNTHESIS AND CHARACTERIZATION OF POLY(VINYL ALCOHOL) NANOCOMPOSITES WITH SILVER NANOPARTICLES."

[34] R. Waleed and E. Al-Bermany, "Advanced toxic gas sensors based on polyvinylpyrrolidone-polypyrrole/graphene oxide-ITO nanocomposites: Enhanced sensitivity toward reducing and oxidizing gases," *Current Applied Physics*, vol. 78, pp. 48–59, Oct. 2025, doi: 10.1016/J.CAP.2025.06.012.

[35] M. V. Nikolic, V. Milovanovic, Z. Z. Vasiljevic, and Z. Stamenkovic, "Semiconductor gas sensors: Materials, technology, design, and application," Nov. 02, 2020, *MDPI AG*. doi: 10.3390/s20226694.

[36] S. Dhall, B. R. Mehta, A. K. Tyagi, and K. Sood, "A review on environmental gas sensors: Materials and technologies," Jan. 01, 2021, *KeAi Communications Co.* doi: 10.1016/j.sintl.2021.100116.

[37] G. J. Thangamani *et al.*, "Graphene oxide nanocomposites based room temperature gas sensors: A review," *Chemosphere*, vol. 280, Oct. 2021, doi: 10.1016/j.chemosphere.2021.130641.

[38] R. Megha *et al.*, "Conducting polymer nanocomposite based temperature sensors: A review," *Inorg. Chem. Commun.*, vol. 98, pp. 11–28, Dec. 2018, doi: 10.1016/J.INOCHE.2018.09.040.

[39] Y. Ding *et al.*, "A Comprehensive Review of Advanced Lactate Biosensor Materials, Methods, and Applications in Modern Healthcare," Feb. 01, 2025, *Multidisciplinary Digital Publishing Institute (MDPI)*. doi: 10.3390/s25041045.

[40] D. Mathivanan *et al.*, "Novel polypyrrole-graphene oxide-gold nanocomposite for high performance hydrogen peroxide sensing application," *Sens. Actuators A Phys.*, vol. 328, Sep. 2021, doi: 10.1016/j.sna.2021.112769.

[41] S. S. A. Kumar *et al.*, "Fabrication and characterization of graphene oxide-based polymer nanocomposite coatings, improved stability and hydrophobicity," *Sci. Rep.*, vol. 13, no. 1, Dec. 2023, doi: 10.1038/s41598-023-35154-z.

[42] Q. Zhu *et al.*, "Epoxy coating with in-situ synthesis of polypyrrole functionalized graphene oxide for enhanced anticorrosive performance," *Prog. Org. Coat.*, vol. 140, Mar. 2020, doi: 10.1016/j.porgcoat.2019.105488.

[43] J. Casanova-Chafer, P. Umek, S. Acosta, C. Bittencourt, and E. Llobet, "Graphene Loading with Polypyrrole Nanoparticles for Trace-Level Detection of Ammonia at Room Temperature," *ACS Appl. Mater. Interfaces*, vol. 13, no. 34, pp. 40909–40921, Sep. 2021, doi: 10.1021/acsami.1c10559.

[44] C. Bora and S. K. Dolui, "Fabrication of polypyrrole/graphene oxide nanocomposites by liquid/liquid interfacial polymerization and evaluation of their optical, electrical and electrochemical properties," *Polymer (Guildf).*, vol. 53, no. 4, pp. 923–932, Feb. 2012, doi: 10.1016/j.polymer.2011.12.054.

[45] S. Raman and A. Ravi Sankar, "Intrinsically conducting polymers in flexible and stretchable resistive strain sensors: a review," Jul. 01, 2022, *Springer*. doi: 10.1007/s10853-022-07479-z.

[46] R. P. Tandel, M. P. Patil, V. S. More, G. G. Padhye, and T. N. Ghorude, "INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY Synthesis and Characterization of PPy-Fe(ClO 4) 2-Ag Nano-Composite and Their Study in H 2 S Gas Sensor at Room Temperature," */ Indian Journal of Science and Technology*, vol. 18, no. 20, pp. 1610–1622, 2025, doi: 10.17485/IJST/v18i20.166.

[47] A. Dube, S. J. Malode, A. N. Alodhayb, K. Mondal, and N. P. Shetti, "Conducting polymer-based electrochemical sensors: Progress, challenges, and future perspectives," *Talanta Open*, vol. 11, p. 100395, Aug. 2025, doi: 10.1016/J.TALO.2024.100395.

[48] M. W. Alam *et al.*, "Recent Progress, Challenges, and Trends in Polymer-Based Sensors: A Review," *Polymers (Basel).*, vol. 14, no. 11, Jun. 2022, doi: 10.3390/polym14112164.

[49] S. Eigler and A. Hirsch, "Chemistry with graphene and graphene oxide - Challenges for synthetic chemists," Jul. 21, 2014, *Wiley-VCH Verlag*. doi: 10.1002/anie.201402780.

[50] G. Kiani, A. Nourizad, and R. Nosrati, "In-situ Chemical Synthesis of Polypyrrole/Silver Nanocomposite for the Use as a Room Temperature Ammonia Gas Sensor," *Fibers and Polymers*, vol. 19, no. 10, pp. 2188–2194, Oct. 2018, doi: 10.1007/s12221-018-8097-z.

[51] M. Cobos, I. De-La-pinta, G. Quindós, M. D. Fernández, and M. J. Fernández, "Graphene oxide–silver nanoparticle nanohybrids: Synthesis, characterization, and antimicrobial properties," *Nanomaterials*, vol. 10, no. 2, Feb. 2020, doi: 10.3390/nano10020376.

भारतीय भाषा, शिक्षा, साहित्य एवं शोध

ISSN 2321 – 9726

WWW.BHARTIYASHODH.COM

INTERNATIONAL RESEARCH JOURNAL OF MANAGEMENT SCIENCE & TECHNOLOGY

ISSN – 2250 – 1959 (0) 2348 – 9367 (P)

WWW.IRJMST.COM

INTERNATIONAL RESEARCH JOURNAL OF COMMERCE, ARTS AND SCIENCE

ISSN 2319 – 9202

WWW.CASIRJ.COM

INTERNATIONAL RESEARCH JOURNAL OF MANAGEMENT SOCIOLOGY & HUMANITIES

ISSN 2277 – 9809 (0) 2348 - 9359 (P)

WWW.IRJMSH.COM

INTERNATIONAL RESEARCH JOURNAL OF SCIENCE ENGINEERING AND TECHNOLOGY

ISSN 2454-3195 (online)

WWW.RJSET.COM

INTEGRATED RESEARCH JOURNAL OF MANAGEMENT, SCIENCE AND INNOVATION

ISSN 2582-5445

WWW.IRJMSI.COM

JOURNAL OF LEGAL STUDIES,POLITICS AND ECONOMICS RESEARCH

WWW.JLPER.COM