

Graphene/Metal Oxide Nanocomposites for Gas Sensing Application

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ABSTRACT

Gas sensors are widely used nowadays for monitoring the atmosphere, detecting dangerous or explosive gases, and in the chemical processing industries. The primary use of gas sensors is the detection of potentially harmful gases that are released into the atmosphere. In order to detect a leak of dangerous gas into the atmosphere, gas sensors are used. This short review is therefore focused on current developments in graphene-based metal oxide composite gas sensing.

Keywords: Graphene, Metal Oxide, Gas Sensing

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INTRODUCTION

Due to its exceptional physical characteristics, including high electronic conductivity, good thermal stability, and excellent mechanical strength, graphene, a two-dimensional, single-layer sheet of sp^2 hybridised carbon atoms, has recently been referred to as "the thinnest material in our universe" [1]. The carbon bonds are sp^2 hybridised, with the in-plane C-C bond being one of the strongest bonds in materials and the out-of-plane bond contributing to a delocalized network of electrons, allowing for weak interactions between graphene layers or between graphene and substrate as well as the electron conduction of graphene. Due to its outstanding physical capabilities and distinctive structural features, graphene has sparked a great deal of research interest in the engineering and scientific fields. The graphene-metal nanoparticle composites have been used in a variety of fields, including surface-enhanced Raman scattering [3], catalysis [4], and electrochemical sensing [5], depending on the kind of attached nanoparticles. Similarly, due to their potential for usage in electronics, optics, and energy-related applications including solar cells, Li-ion batteries, and supercapacitors, there is high demand for the production of graphene-semiconductor nanomaterial composites.

Literature Survey

Most of the gas sensors reported in literature generally operated in the resistive mode, where the change in sensor resistance with exposure to the gas is measured directly. This type of sensor is also known as chemiresistive sensors

[6, 7]. This kind of sensor is simple with ease of fabrication and direct measurement capability. Graphene based sensors also follow such type of device construction. In most of the graphene based chemiresistor, the resistance is measured either directly or from the current/voltage characteristics between the two contacts taken from the top of the sensing graphene films [8, 9]. The immediate competitor of graphene in the evolution of new and promising materials for gas sensors is carbon nanotube (CNT) which showed promising structural and electrical properties for chemical sensor applications. But one fundamental feature of CNT is its one-dimensional structure, which is not appropriate to use as gas sensing material. This problem was overcome after the discovery of graphene that is 2D structure of one atomic thick carbon atom having all the interesting properties of CNT. Since graphene is a two-dimensional material, every atom of graphene may be considered a surface atom and as a result every atom site may be involved in the gas interactions [10-12].

Leenaerts et al studied the charge transfer characteristics between the gases like NH_3 , CO , NO_2 , and NO with graphene. This study shows that gas sensing was almost independent on the adsorption site but it depends strongly on the orientation of the gaseous molecule with respect to the graphene surface [13]. Gautam et al investigated the gas sensing properties of CVD grown monolayer graphene for NH_3 and oxygen detection. In this study, the authors found that the electrical conductivity of graphene is sensitive to the

reducing gases at high temperatures. The sensing response of the device towards tested gases suggested that the device was most effective to operate in 150–200 °C range [14–16]. Reduced graphene oxide was used to improve the hydrogen sensing properties of Pd and Pt-decorated TiO₂ nanoparticles by Esfandiari et al [17]. Gas sensing was studied with different concentrations of hydrogen ranging from 100 to 10,000 ppm at various temperatures. High sensitivity (92%) and fast response time (less than 20 s) at 500 ppm of hydrogen were observed for the sample with low concentration of Pd (2 wt.%) decorated on the TiO₂/RGO sample at a relatively low temperature (180 °C). Lin et al [18] synthesized SnO₂/graphene composite via a simple one-pot hydrothermal method with graphene oxide (GO) and SnCl₂ as the precursors. Under optimal conditions, the composite displayed high response magnitude (15.9% for 50 ppm NH₃), fast response (response and recovery time < 1 min), good reversibility and repeatability. Chu et al [19] reported the synthesis of epitaxial graphene through CVD on SiC, coated with Pt, it acted as dopant and decreased the resistivity of graphene. Gas sensing results showed that exposure to hydrogen decreased the resistance of the graphene/Pt as a function of temperature. Ko et al [20] focused on the selectivity problem of gas sensors and resolved this by depositing Pd/Au electrode on graphene for sensing NO₂. Lange et al investigated graphene-Pd nanocomposite with Au electrode for H₂ detection [21]. The graphene-Pd nanocomposite was found to be capable of sensing hydrogen at levels from 0.5 to 1% in synthetic air. Pristine graphene is poorly sensitive towards hydrogen, but incorporation of Pd enhanced its sensitivity. Yi et al [22] fabricated the flexible gas sensors, composed mainly of a bottom ZnO conductive layer on metal foil, vertically aligned ZnO nanorod channel, and graphene-based top conductive electrode. Multiple cycling tests demonstrated the ZnO nanorods (NRs) and graphene (Gr) hybrid architectures accommodated the flexural deformation without mechanical or electrical failure for bending radius below 0.8cm under the repeated bending and releasing up to 100 times. Gas sensors demonstrated the ppm level detection of ethanol gas vapor with the sensitivity (resistance in air/resistance in target gas) as high as ~9 for 10ppm ethanol. The graphene with gold electrode was investigated for its CO₂ sensing by Yoon et al [23]. Sensor showed fast response (~10 s) and reproducible response to CO₂ at room temperature with high sensitivity and low power consumption.

Gas Sensing

Due to its widespread usage in cooking and heating, LPG detection nowadays is also crucial. LPG is an excellent energy source that burns cleanly, but because of its high flammability, it poses risks to people. Since LPG cannot be seen and has no natural odour, a special odour is supplied to help find any leaks. Because of its extreme explosivity, even very low concentrations (ppm) result in major issues. Therefore, it's crucial to detect it at its lowest concentrations with great accuracy.

The continual exchange of carbon dioxide (CO₂) between the atmosphere, ocean, and soil surface makes it a crucial component of the earth's atmosphere. Ocean acidification and climate change are both caused by the ocean absorbing CO₂ from the atmosphere.

Solid-state gas sensors based on semiconducting metal oxide take use of the fact that gas may alter the semiconductor's electrical conductivity by altering the surface charge carrier

concentration. This detection system will aid in monitoring dangerous gases and identifying the atmospheric gas concentration threshold [24–25].

Conclusions

One of the most intriguing materials is graphene, both for its potential use and for the scholarly attention it has generated. High electron mobility at normal temperature, exceptional thermal conductivity, and improved mechanical characteristics with a high Young's modulus are just a few of the intriguing qualities that graphene has demonstrated. Since graphene has peculiar electrical, thermal, and mechanical properties, it is anticipated that it will find use in a wide range of products, including field-effect transistors, memory systems, photovoltaic devices, sensors, supercapacitors, batteries, and hydrogen storage systems. These characteristics provide graphene a wide variety of uses.

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