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The Art of Building a Good Chemiresistive Sensor Based on AC: Tips and Tricks for Better Detection Performance

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Summary:

Due to rising air pollution, gas sensors have become essential in fields such as industry, medicine and environmental monitoring. This work presents advancements in gas-sensing technologies, emphasizing the role of activated carbons (ACs) and their hybrids. ACs are gaining interest thanks to their high surface area and porous structure, which enhance gas adsorption. Their surfaces can be modified with additives or combined with other materials to improve sensor performance. The present communication highlights the sensing performance of AC-based gas sensors, and future challenges in this field.

Keywords: Activated carbon (AC), Gas sensors, Hybrids, Porosity, Surface area

Background, Motivation and Objective

Figs. 1 and 2 illustrate the number of publications from 2000 to 2024, based on the literature reviewed. From the data presented in these figures, it is evident that research on the development of AC-based materials for chemical gas sensing, particularly for air pollution monitoring, has remained relatively limited attention until recent years. Given the growing focus on developing chemical gas sensors with highly porous, sensitive and highly selective sensing layers, with a fast gas detection rate, operating at room temperature and inexpensive, a comprehensive review of AC-based sensors is both timely and necessary. Such a review can help to identify the challenges associated with the application in gas sensing.

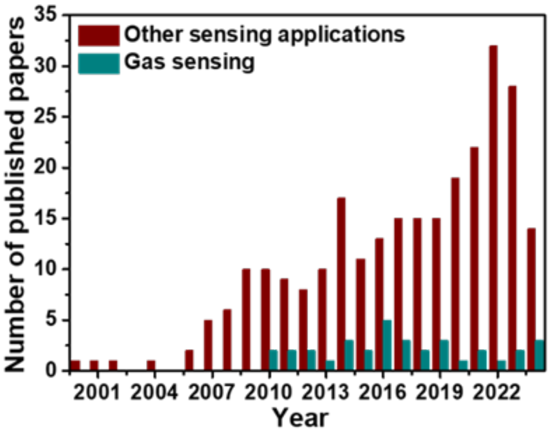

Fig. 1. Number of articles published on AC-based materials for sensing since 2000, obtained from the SCOPUS database.

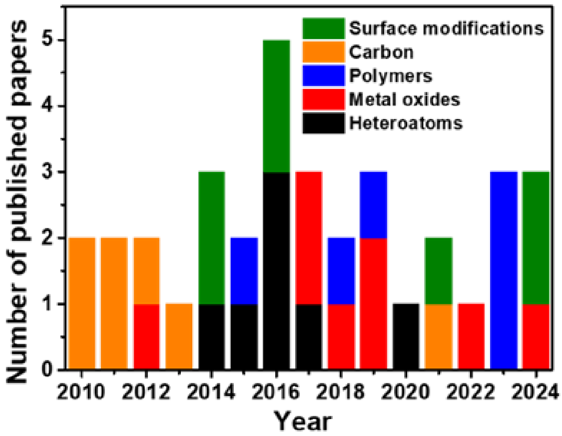

Fig. 2. Number of papers reviewed in which AC was combined with various materials for gas sensing applications.

The objective of this work is to examine the latest progress in gas sensors based on AC used as sensitive layers, with particular focus on hybrid composites formed by combining AC with other materials, to improve sensor performance.

About AC-based gas sensors in general

AC is characterized by a complex 3D network of aromatic nano-domains (2–3 nm in size) [1], comprising narrow pores. Each nano-domain typically consists of a stack of 3–4 graphene-like sheets, each measuring approximately 3 nm or less [2]. This structural characteristic provides an exceptionally high surface area (up to 3000 $m^2.g^{-1}$), which offers numerous active sites for the adsorption of large quantities of gas molecules [3]. Despite these advantages, AC has certain limitations, including low recovery and recyclability, as well as moderate electrical conductivity. In comparison, graphene-based materials can exhibit electrical conductivities on the order of 10^4 $S.cm^{-1}$ [4], whereas AC typically shows a lower conductivity in the range of 20–50 $S.cm^{-1}$ [5], leading to limited charge transfer at the carbon surface [6]. To overcome these drawbacks, it is critical to modify the AC surface with other materials such as metal oxides, conducting polymers, heteroatoms or other carbons. These modifications enhance critical properties such as conductivity and recoverability, which are essential parameters for gas sensor applications [7].

a) AC doped with heteroatoms

The enhanced gas sensing performance of heteroatom-modified activated carbons can be primarily attributed to changes in their surface chemistry. The incorporation of heteroatoms such as boron (B), nitrogen (N), oxygen (O) and sulfur (S) can: ***(1)*** improve the electrical properties of AC; ***(2)*** facilitate more efficient charge transfer interactions between ACs and target gases; ***(3)*** improve the surface reactivity by providing more active sites for gas adsorption; and ***(4)*** introduce various functional groups on the AC surface, which significantly enhance selectivity and sensitivity toward specific gases.

b) AC-metal oxide hybrid materials

The combination of AC and metal oxides takes advantage of: ***(1)*** the high surface area and adsorption capacity of AC; and ***(2)*** the excellent gas-sensing properties of metal oxides. Many metals oxides function as semiconductors and exhibit changes in their electrical properties upon gas exposure. When integrated with AC, the formation of heterojunctions between these material interfaces act as electron transfer pathways, thereby improving charge carrier mobility. Additionally, the porous structure and high surface area of AC provide an ideal support matrix for the uniform dispersion of metal oxide, further enhancing the overall sensing performance.

c) AC-polymer composites

AC enhances the performance of polymer-based gas sensors by increasing surface area, thereby offering numerous adsorption sites for gas molecules. The porous structure of AC helps trapping gas molecules, allowing the polymer matrix to interact with a higher density of analytes. These characteristics make AC–polymer composites highly effective for a broad range of gas-sensing applications.

d) Composites of AC with other carbon materials

The detection performance of AC-based composites combined with other carbonaceous materials is generally attributed to the high specific surface area and porous structure of AC, which significantly enhance the overall adsorption capacity of the composites. Moreover, when AC is combined with highly conductive carbon materials such as carbon black, graphene or carbon nanotubes, efficient conductive networks are formed. These networks can: ***(1)*** increase the overall electrical conductivity of the composites; and ***(2)*** improve their response to gas adsorption.

Conclusion

This work summarizes AC-based gas sensors and explores their integration with various other sensing materials, including heteroatom-doping, metal oxides, alternative carbon materials and polymers, which contribute to enhanced gas sensing performance.

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