

Pd Decorated Mesoporous TiO₂ Nanospheres for High Performance Hydrogen Gas Sensors at Room Temperature

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Summary:

A highly sensitive and selective hydrogen gas sensor operating at room temperature was developed using palladium decorated mesoporous titanium dioxide nanospheres. The sensor was fabricated via a combination of solvothermal and chemical reduction methods to enhance surface area and improve gas surface interactions. The sensor exhibited a high response of 504% with a fast response (35 s) toward 1000 ppm hydrogen at room temperature. In addition, the sensor demonstrated a wide detection range (50-10,000 ppm), with linearity ($R^2:0.9912$) at low concentrations.

Keywords: Nanospheres, Hydrogen, Titanium dioxide, Room temperature, Pd catalyst.

Background, Motivation and Objective

Hydrogen is widely recognized as a clean energy carrier; however, its high flammability (4-75%) and broad explosive range demand highly reliable sensing technologies for safe handling and practical deployment. Traditional hydrogen sensors often require elevated operating temperatures and commonly show limitations in response time, stability, and power consumption, which restricts their real-world applicability. Metal oxide semiconductors such as TiO₂ have been extensively studied for gas sensing applications due to their chemical stability, low cost, and versatile nano structuring capability. Nevertheless, pure TiO₂ generally exhibits weak sensing performance at room temperature (RT) because of limited surface reaction activity and slow charge transport processes [1].

To overcome these challenges, modification with noble metals has been widely adopted to improve sensing efficiency. Palladium is particularly effective due to its strong catalytic affinity toward hydrogen, enabling efficient dissociation of hydrogen molecules and enhanced electron transfer at the sensing interface [2]. In addition, the mesoporous architecture offers a large specific surface area, which increases the availability of active sites and facilitates rapid diffusion of gas molecules within the sensing layer.

In this study, Pd modified mesoporous TiO₂ nanospheres are designed and developed for hydrogen sensing applications. The main objective is to investigate the combined influence of Pd decoration and mesoporous nanospherical structure

on the sensing characteristics, including response magnitude, response time, and RT operation. This work aims to establish an efficient sensing platform enabling high-performance hydrogen detection at RT.

Description of the New Method or System

Pd decorated mesoporous TiO₂ nanospheres were synthesized using analytical grade precursors through a combination of solvothermal processing and chemical reduction methods. Hexadecylamine was employed as a surfactant to direct the formation of a mesoporous shell structure on the TiO₂ nanospheres. The solvothermal treatment was subsequently conducted in an autoclave at 160 °C for 16 hr to facilitate the removal of the surfactant and stabilize the mesoporous architecture.

Results

According to the transmission electron microscope (TEM) images (Fig. 1(a-b)) shows well defined mesoporous TiO₂ nanospheres decorated with randomly distributed Pd nanoparticles. The darker contrast regions correspond to Pd nanoparticles (3.24 ± 0.22 nm) anchored on the surface of the TiO₂ nanospheres. In addition, a highly porous internal structure is clearly observed, confirming the successful formation of nanopores within the nanospheres. The presence of these nanopores provides a large accessible surface area, which is beneficial for hydrogen gas adsorption and diffusion.

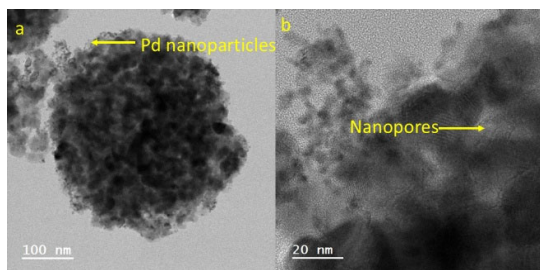


Fig.1. TEM images of (a) Pd-decorated mesoporous TiO_2 nanospheres showing randomly distributed Pd nanoparticles on the nanosphere surface and (b) a well-developed porous network with visible nanopores.

According to Fig. 2, the synergistic effect of Pd nanoparticles and the mesoporous architecture of TiO_2 nanospheres enables the sensor to achieve a high response of 504% (Equation 1), with a rapid response of 35 s toward 1000 ppm hydrogen at RT.

$$R\% = \left(\frac{I_{\text{gas}} - I_{\text{air}}}{I_{\text{air}}} \right) \quad (1)$$

Where; R : response magnitude, I_{air} : Current of the sensor in the baseline condition and I_{gas} : Current of the sensor in hydrogen environment.

Response time: The time taken to increase the baseline current to 90% of current change after exposure to hydrogen gas.

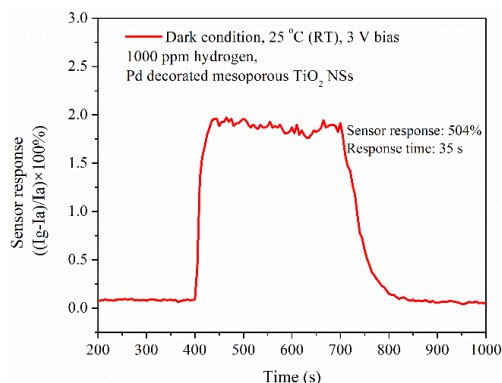


Fig.2. Hydrogen sensing performance of Pd decorated mesoporous TiO_2 nanospheres at RT under 3 V bias.

Fig. 3 shows that the sensor response increases progressively with hydrogen concentration up to 4000 ppm, reaching a current value of 3.17 μA , and then further rises to approximately 4.39 μA at 10,000 ppm, where it begins to plateau, suggesting saturation due to the occupation of most active surface sites on the sensing material. This trend is consistent with Langmuir-type adsorption behavior [3].

Furthermore, Fig. 4 shows that at low hydrogen concentrations (0-4000 ppm), the response exhibits strong linearity ($R^2 = 0.9912$), enabling precise detection in the low concentration range, which is critical for early hydrogen leak detection.

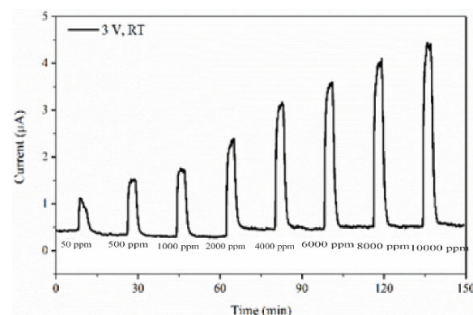


Fig.3. Hydrogen sensing performance towards hydrogen with different concentrations (50–10,000 ppm) at RT under 3 V bias.

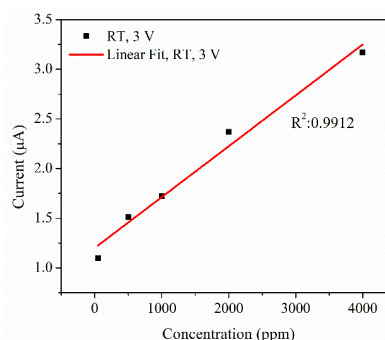


Fig.4. Linear fit of sensor response at RT with corresponding R^2 value.

Conclusion

Pd decorated mesoporous TiO_2 nanospheres enable highly sensitive, fast, room temperature hydrogen sensing for practical applications.

Acknowledgements

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