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Pd Decorated MoS_2 Nanosheet Deposited on Yolk-Shell (SiO_2-TiO_2) Nanosphere for Hydrogen Gas Sensing

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Summary:
In this research, we explore a highly sensitive chemiresistive hydrogen gas sensor based on Pd-decorated MoS_2 nanosheets deposited on yolk–shell (SiO_2–TiO_2) nanospheres. This novel architecture was synthesized using a two-step facile hydrothermal method. The sensor shows a response of 317.3 towards 10,000 ppm hydrogen at 30 °C under a 9 V bias, with response and recovery times of 78 s and 39 s, respectively. The synergistic effect of Pd nanoparticles and MoS_2 deposited on the yolk–shell structure enhances the sensor performance and confirms its capability for real-world hydrogen sensing applications.

Keywords: Molybdenum disulfide, Pd nanoparticles, hydrogen sensor, yolk-shell structure.

Background, Motivation and Objective

Hydrogen plays an important role as a clean and sustainable energy carrier and has significant potential to replace fossil fuels [1]. It is widely used across various industries, including ammonia and methanol synthesis, water splitting, fuel cells, aerospace and medical applications. However, hydrogen is highly flammable and explosive, which limits its safe use. Therefore, reliable hydrogen gas sensors are essential for real-time detection to mitigate these risks. Existing hydrogen gas sensors suffer from many issues including higher operating temperatures, low response and recovery [2]. Hence, to overcome these limitations, new sensor materials need to be developed. Molybdenum disulfide (MoS_2) has gained significant attraction for gas sensing applications due to its intrinsic properties, such as higher surface to volume ratio, ability to functionalized with other materials, tunable band gap and flexibility to integrate in to modern electronics [3]. This research explores synthesis of a novel material, Pd decorated MoS_2 nanosheets deposited on yolk-shell (SiO_2-TiO_2) nanospheres (NS) (Pd@MoS_2 YS(SiO_2-TIO_2) NSs) for hydrogen sensing. This architecture provides a solid core, internal void space, and a porous shell, which facilitates a higher surface to volume ratio and enhances hydrogen adsorption.

Method

S two step hydrothermal method was used to synthesize Pd@MoS_2 YS(SiO_2-TIO_2) NSs. Initially, monodispersed SiO_2 NSs were synthesized using the Stöber method [4], which were then coated with TiO_2 to obtained yolk-shell NSs using a hydrothermal method and calcination. Subsequently, two-dimensional (2D) MoS_2 nanosheets were deposited on the YS NSs using a hydrothermal method. Finally, Pd nanoparticles were deposited via a simple reduction method.

Results

According to the scanning electron microscope (SEM) and transmission electron microscope (TEM) images shown in Fig. 1 (a), the presence of a well-defined spherical morphology with an internal SiO_2 yolk and TiO_2 shell structure with approximate diameters of 106 nm and 299 nm, respectively is confirmed. Furthermore, Fig. 1 (b) shows Pd-decorated MoS_2 nanosheets deposited on yolk–shell (SiO_2–TiO_2) NSs, along with the formation of a void space and a porous shell. This unique architecture provides a higher surface to volume ratio, allowing more hydrogen to be adsorbed for enhancing sensor performance. Energy-dispersive X-ray spectroscopy (EDS) mapping shown in Fig. 1 (c-f) demonstrates the uniform distribution of elements throughout the NSs.

The sensing performance of the synthesized Pd@MoS_2 YS (SiO_2–TiO_2) NSs were evaluated using a custom-built, fully automated gas chamber. The sensor response (R) was calculated using Equation (1), where I_{air} and I_{gas} represent the sensor current in air and under hydrogen exposure, respectively.

$$R = \frac{(Igas - Iair)}{Iair} \quad (1)$$

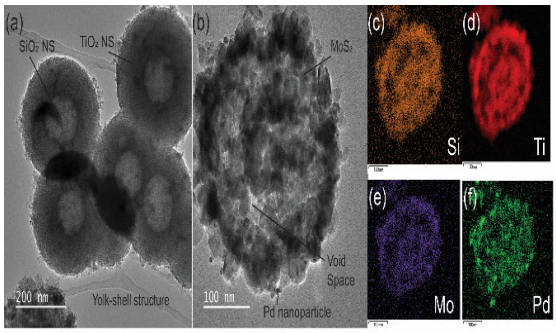


Fig. 1. (a-b) TEM images of yolk-shell (SiO_2 -TiO_2) NS and Pd@MoS_2 YS (SiO_2-TIO_2) NS, corresponding EDS elemental mapping: (c) Si (d)Ti (e) Mo and (f) Pd.

According to Fig. 2 (a) the sensor response was analyzed for hydrogen (500 -10,000 ppm) at different operating temperatures (25 °C, 30 °C, 40 °C, and 50 °C) under a 9 V bias. The sensor (Fig. 2 (b)) showed a response of 317.3 towards 10,000 ppm hydrogen at 30 °C, with a response time of 78 s and a fast recovery of 39 s. Furthermore, the sensor illustrated a noticeable response of 3.61 at a lower hydrogen concentration of 1,000 ppm. Sensitivity, calculated from the linear region (2000-8000 ppm) was approximately 0.038 ppm^{-1}, indicating correlation between sensor response and concentration. The significant sensor response is attributed to the synergistic effect of Pd nanoparticles and MoS_2 nanosheets, where Pd nanoparticles act as a catalyst for hydrogen molecule dissociation forming PdH_x, and the 2D MoS_2 nanosheets heterojunction with TiO_2, provides more active sites and enhancing charge transfer efficiency [5]. Further, corresponding linear fitting curves at 30 °C and 40 °C (Fig. 2 (c)) demonstrate good linearity, with R^2 values of 0.96 and 0.97, respectively. All these results conclude that novel Pd@MoS_2 YS (SiO_2–TiO_2) NS sensor is promising and has potential for real world applications.

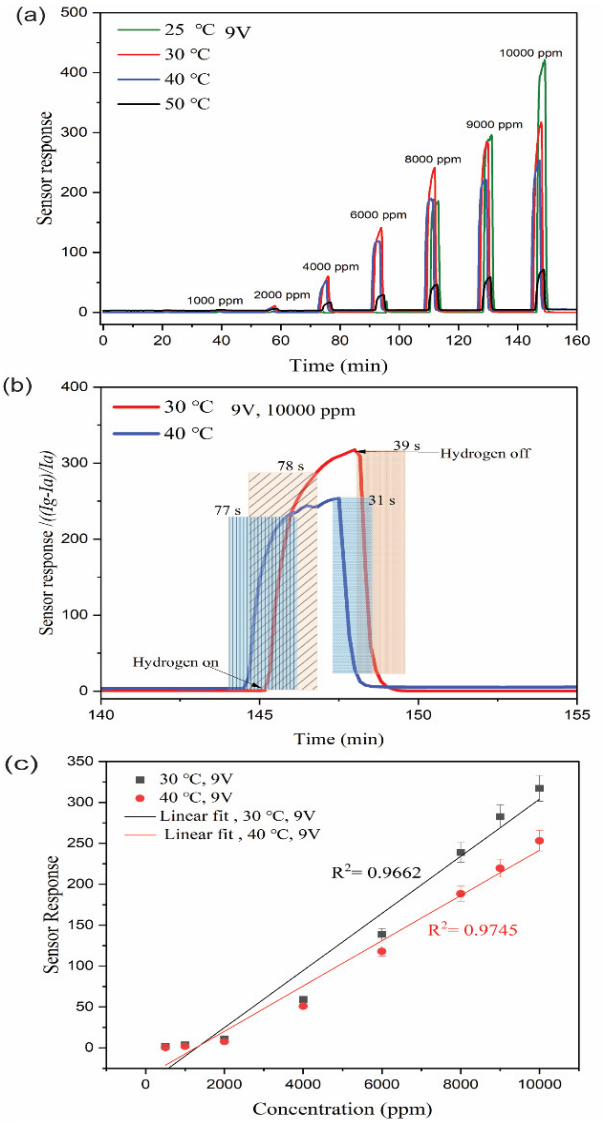


Fig. 2. Dynamic response towards hydrogen: (a) at different operating temperatures, (b) response and recovery times at 10,000 ppm, and (c) calibration curves at 30 °C and 40 °C.

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