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Pd Nanoparticles Decorated TiO_2 Nano-spheres for Hydrogen Gas Sensing at Room Temperature under Visible Light Conditions

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Summary:
Visible light active hydrogen sensor can operate at ambient temperatures with enhanced performance making them a promising candidate for real-world applications. In this study, such sensor has been fabricated that employ heterojunctions containing Pd nanoparticles (NPs) decorated on TiO_2 nanospheres (Pd-decorated TiO_2 NS) using facile chemical methods. The sensor shows a response of 100.88% towards hydrogen with fast response and recovery (77 s and 470 s, respectively) at 30 ℃ under 565 nm visible light conditions and a voltage bias of 0.5 V.

Keywords: Nanoparticles, Nanospheres, Hydrogen sensing, Visible light, Room temperature.

Introduction

Hydrogen gas sensing has become important in recent times due to the increasing usage of hydrogen as an alternative energy source and feedstock. Hydrogen is highly flammable and explosive [1] and can pose a significant risk to human and environment safety in the event of leaks. Sensors that can detect hydrogen at low levels accurately and in real-time can prevent such incidents and ensure safe usage of hydrogen. Furthermore, development of hydrogen sensors contributes to advance the hydrogen economy and the adoption of hydrogen as a sustainable energy source [2].

Titanium dioxide (TiO_2) is widely used as a sensing material for hydrogen due to its high chemical stability and sensitivity to hydrogen gas. Additionally, TiO_2 is a low cost, abundant, and environmentally friendly material, making it an attractive choice for hydrogen sensing applications.

Sensors making use of visible light and operating at room temperature are generally more cost-effective compared to other types of hydrogen sensors, which can be expensive to produce and maintain. Therefore, in this endeavour, we aim to develop a hydrogen gas sensor with enhanced performance that can work at room temperature utilizing visible light.

Novelty

TiO_2 is an environmentally friendly sensing material, and the use of visible light instead of heat or other sources of energy makes these sensors more environmentally friendly compared to other types of hydrogen sensors that require low power [3]. In this work, we have successfully fabricated novel visible light active hydrogen sensing material that shows enhanced performance at 30 ℃ under voltage bias of 0.5 V.

Results and Conclusion

Figure 1 shows SEM image of the Pd-decorated TiO_2 NS. Monodispersed, agglomeration free, rigid TiO_2 nanospheres can be seen in the SEM image. The XRD analysis confirmed successful synthesis of Pd NPs decorated on the TiO_2 NS.

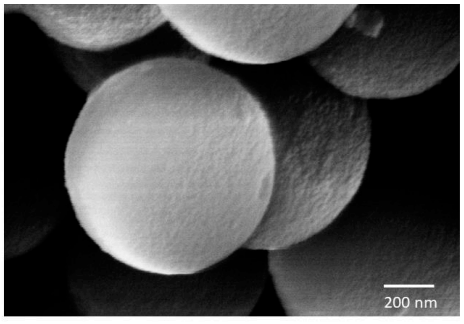

Fig. 1. SEM image of synthesized Pd-decorated TiO_2 NS.

To analyze hydrogen sensing properties, the operating temperature was optimized under dark and 565 nm visible light conditions. The sensor works at an optimum temperature of 50 ℃ under the dark condition with a response of

101.26% (using eq. (1)). However, the response (135 s) and recovery (1345 s) (Fig. 2) are significantly longer as compared to the condition under 565 nm visible light. When introducing 565 nm visible light to the sensor, a significant enhancement in response time (77 s) and recovery time (470 s) can be seen (Fig. 3). Furthermore, the working temperature was reduced from 50 ℃ to 30 ℃ under the light condition.

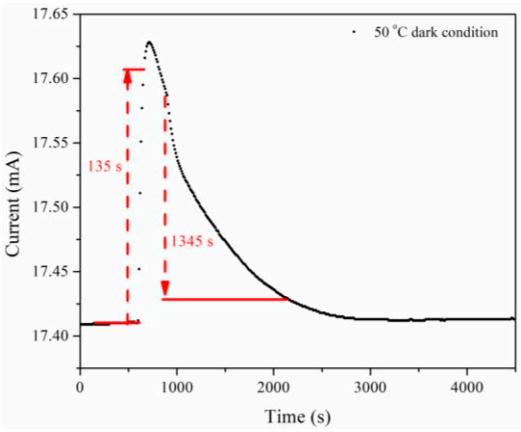

Fig. 2. Sensor response and recovery time towards 500 ppm hydrogen at 50 ℃ under dark conditions and 0.5 V.

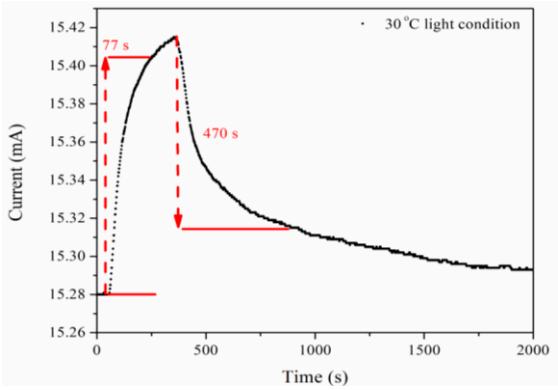

Fig. 3. Sensor response and recovery time towards 500 ppm hydrogen at 30 ℃ under 565 nm light conditions and 0.5 V.

Hydrogen sensing mechanism was studied to better understand the material behaviour at different conditions. Under the dark conditions, oxygen molecules presence in the air capture the electrons on the TiO_2 surface and form chemisorbed $O^-_{2(ads)}$. However, under 565 nm visible light the chemisorbed oxygen ion species react with photogenerated holes and electrons (due to the lowering the band gap energy) and generate photoinduced oxygen species that are loosely bound on the TiO_2 surface [4]. Therefore, loosely bound oxygen species easily reacts with hydrogen via $O^-_{2(h\nu)} + H_2 \rightarrow H_2O + e^-$ [5]. Under the dark conditions heat or another energy sources needs to be applied to desorb the chemically bound oxygen species on the TiO_2 surface. Therefore, under the dark condition 50 ℃ was required to activate the sensing layer. Furthermore, the Pd NPs act as a hydrogen collector as well as hydrogen dissociation agent to enhance the hydrogen sensing properties as follows; $Pd + \frac{x}{2}H_2 \rightarrow PdH_x$ and $2PdH_x + \frac{x}{2}O^-_{2(h\nu)} \rightarrow 2Pd + xH_2O + xe^-$.

According to the results, this study confirms development of novel nanomaterials for high performing gas sensors operating at a low temperature under visible light conditions that are promising for real-world applications.

Equations

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

R: response magnitude.

I_{air}: Current of the sensor in the baseline condition.

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.

Recovery Time: The time taken to decrease the sensor current 90% back to the baseline current.

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