DOI 10.5162/IMCS2018/P2GS.18

Gas Sensing Characteristics of Phosphorus-decorated Molybdenum Disulfide Thin Films

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Abstract
In this work, we synthesized phosphorus-decorated MoS_2 thin films as material for gas sensor through a solution process and chemical vapor deposition. Phosphorus-decorated MoS_2 showed the higher gas sensing performance than the bare MoS_2 thin films. With this method, higher sensitivity and selectivity can be achieved, resulting in the broad application of MoS_2-based gas sensors.

Key words: Gas sensors, 2D TMDs, MoS_2 thin film, phosphorus, Internet of Things

Introduction

In recent days, internet of things (IoT) has increased enormous attentions and one of the most arising research areas on IoT is the gas sensor. The gas sensors play an essential role in various fields. To meet IoT requirements, the ease of integration of electronic circuits with low cost, small size and high sensing performances are crucial for gas sensors [1]. Among various types of gas sensors, chemoresistive gas sensors based on semiconductors have been considered as most applicable candidates for the IoT because of their low cost and small size [2].

Two-dimensional (2D) materials are noteworthy because their characteristics, such as high surface-to-volume ratios and easy device fabrication are suitable to be applied as the active material of the gas sensors [3]. Since many transition metal disulfides, such as MoS_2, WS_2 and SnS_2, are semiconducting with tunable bandgap energies depending on the thickness, the transition metal disulfides are inherently more desirable than graphene, metallic with zero band gap energy, for chemoresistive gas sensing applications [4]. In particular, MoS_2 exhibited impressive gas sensing performances due to its high surface-to volume ratio, semiconducting properties, and plentiful active edge sites [5]. However, despite the increased interest and the diverse studies, the study of the relationship between the gas detection mechanism and the edge sites of 2D MoS_2 have not been clarified.

Therefore, in order to discover the specific sensing mechanism, we synthesized phosphorus-decorated MoS_2 by the chemical vapor deposition (CVD) method and solution process. Since the MoS_2 is the 2D material, the decoration effect is expected to be higher than 3D materials. Therefore, decorating the MoS_2 thin films with various materials can lead to unpredicted unique results.

Method

Pt interdigitated electrodes (IDE) were prepared and used as substrates for the sensor applications. The phosphorus-decorated MoS_2 thin films were synthesized on the 1 mm x 1 mm size active area on the Pt IDE. The solution process and the CVD process were used to synthesize the P-decorated MoS_2 thin films.

The sensing performances of the gas sensor based on the P-decorated MoS_2 thin films were measured in a gas measuring device with a quartz tube and a furnace. The variations of the resistance were measured while the flowing gases were changing from dry air to the target gases with a source measurement unit. The mass flow controllers controlled the exact amount of gas flow, maintaining the constant flow rate of 1000 sccm.

Results and Discussion

Fig. 1 shows the response curves to 50 ppm C_2H_5OH at 250 ^oC for MoS_2 and phosphorus-decorated MoS_2. Compared with the gas sensor based on the bare MoS_2 thin films, the gas sensor based on the P-decorated MoS_2 thin films showed 50 times higher response for C_2H_5OH detection.

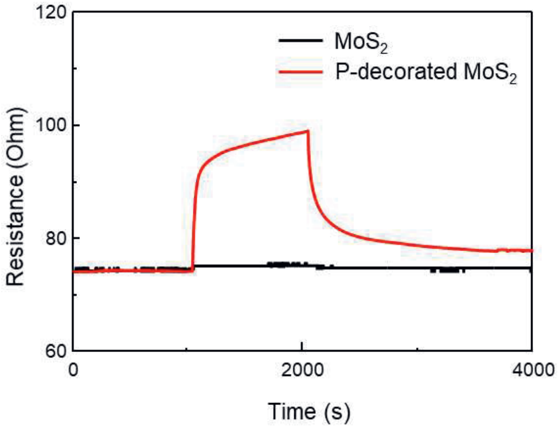

Fig. 1. Response curves of bare MoS_2 and phosphorus-decorated MoS_2 thin films to 50 ppm C_2H_5OH at 250 °C..

Fig. 2 shows the responses of the P-decorated MoS_2 thin films to 50 ppm C_2H_5OH, CH_3CHO, C_6H_6, H_2, CH_3COCH_3, and 5 ppm NO_2 at 250 °C.

The response of the sensor was calculated by eq. (1),

$(R_{gas}-R_{air})/R_{air} = \triangle R/R_a$ (1)

Where, R_{air} is the base resistance of the gas sensor in air condition and R_{gas} is the resistance when the target gas was fully adsorbed. The sensor showed the second highest response to CH_3CHO and the response to C_2H_5OH was three times higher than the response to CH_3CHO. These results indicate that the P-decorated MoS_2 thin film is beneficial for the selective C_2H_5OH detection.

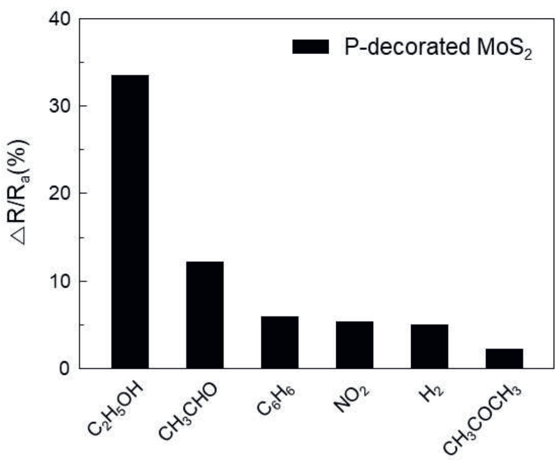

Fig. 2. Gas responses of phosphorus-decorated MoS_2 thin films to 50 ppm C_2H_5OH, CH_3CHO, C_6H_6, H_2, CH_3COCH_3, and 5 ppm NO_2 at 250 °C.

Conclusion

We have investigated gas sensors based on phosphorus-decorated MoS_2 thin films. The dangling bonds and base resistances were changed by the phosphorus atoms, resulting in the variation of the sensing performances. The sensor has the highest response to C_2H_5OH and the selective characteristic at 250 °C. Since the MoS_2 is the 2D material, more unprecedented sensing properties can be studied with the additional noble metal decoration which can broaden the potential of MoS_2-based gas sensors.

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