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Synthesis of 2-Dimensional WS_2 Nanoflakes with NO_2 Selectivity at Room Temperature

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Summary:

We have synthesized 2-dimenstional (2D) WS_2 nanoflakes utilizing chemical vapor deposition to detect hazardous and harmful gas species at room temperature. The synthesized WS_2 nanoflakes were characterized via scanning electron microscopy, transmission electron microscopy, X-ray diffraction, X-ray photoelectron spectroscopy, and Raman spectroscopy. In addition, to verify the detection of hazardous and harmful gases at room temperature, we systematically investigated the gas sensing performances of 2D WS_2 nanoflake-based gas sensors using NO_2, NH_3, C_2H_5OH, C_3H_6O, and H_2 gases. Although the 2D WS_2 nanoflakes showed lower NO_2 response than that of a similar exfoliated WS_2 nanoflakes, unlike the exfoliated WS_2 nanoflakes, the 2D WS_2 nanoflakes exhibited good NO_2 selectivity. These results indicate that the CVD-grown 2D WS_2 nanoflakes can be applicable to sensing material for detecting NO_2 at room temperature.

Keywords: 2-dimensional WS_2, chemical vapor deposition, gas sensing, room temperature, NO_2 selectivity

Background, Motivation an Objective

In modern society, highly sensitive and selective gas sensors that can quickly detect hazardous and harmful gases are necessary to a variety of applications, including air quality monitoring [1], tracking exhaust emissions for vehicles [2], preventing crops from the pests [3] and disease diagnoses [4].

Among the different gas species, in particular, nitrogen dioxide (NO_2) is well known as a poisonous and fatal to human beings even exposure to as low as ppm-level. Additionally, NO_2 gas molecules easily react with other chemicals in the atmosphere, resulting in the acid rain, ozone layer depletion, and global warming. Hence, development of highly sensitive and selective NO_2 gas sensors is urgent.

In recent decades, the semiconducting material-based gas sensors have attracted considerable interest because of their excellent properties, such as high response, thermal stability, miniaturization, compatibility with electronics, and applicability for mass production [5,6]. However, to detect the gas molecules utilizing semiconducting material-based gas sensors, the high temperature (> 200℃) should be needed, causing the huge power consumption. Furthermore, selectivity for certain gas molecules is also important parameter in practice gas sensor applications. Therefore, we attempted to implement the gas sensors operating at room temperature with NO_2 selectivity.

In this present, we successfully fabricated NO_2 gas sensors based on 2-dimenstional (2D) WS_2 nanoflakes utilizing the chemical vapor deposition (CVD). The fabricated sensors showed the best NO_2 response at room temperature compared to NO_2, NH_3, C_2H_5OH, C_3H_6O, and H_2 gases.

Description of the New Method or System

To synthesize the 2D WS_2 nanoflakes, WO_3 and sulfur powder were used as precursors and hydrogen (99.999%) gas was used as a carrier gas. We systematically investigated the sensing performances of CVD-grown 2D WS_2 nanoflakes at room temperature, compared to those of exfoliated WS_2 nanoflakes. Interestingly, CVD-grown 2D WS_2 nanoflakes exhibited good NO_2 selectivity while exfoliated 2D WS_2 nanoflakes relatively showed poor gas selectivity.

Results

Fig. 1 shows the results of transmission electron microscopy (TEM) of CVD-grown 2D WS_2 nanoflakes. As shown in Fig. 1(a), the 2D

WS$_2$ nanoflakes consist of a few layers of WS$_2$ nanosheets. Fig. 2(b) exhibits the high-resolution TEM image of 2D WS$_2$ nanoflake, indicating high quality of crystallinity.

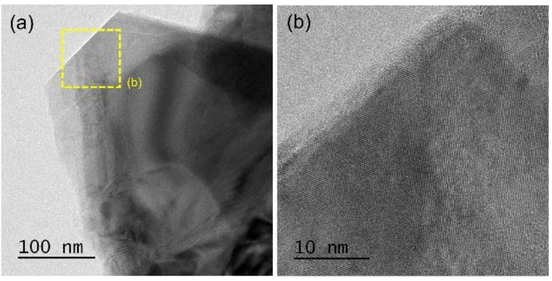

Fig. 1. TEM images of 2D WS$_2$ nanoflakes

In addition, the component analysis were also conducted utilizing the energy-dispersive spectroscopy (EDS) equipped with TEM. The EDS results clearly show that the 2D WS$_2$ nanoflakes were successfully synthesized (Fig. 2). The EDS results are in agreement with X-ray diffraction result (not shown in this abstract).

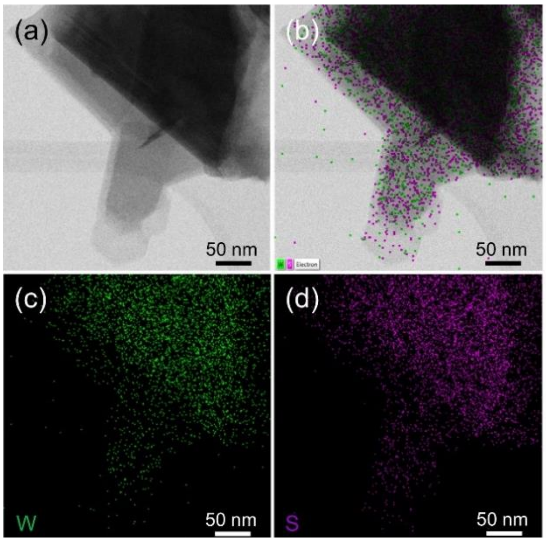

Fig. 2. The EDS results of 2D WS$_2$ nanoflakes

The sensing performances of 2D WS$_2$ nanoflakes were systematically investigated at room temperature, compared to exfoliated 2D WS$_2$ nanoflakes. The all gas responses in this study were calculated using following equation:

$$S(\%) = \frac{R_{air} - R_{gas}}{R_{air}} \times 100$$

, where R_{air} and R_{gas} are the resistance when exposing to air and target gas, respectively. The transient NO_2 response curves of 2D WS$_2$ nanoflakes measured at room temperature are shown in Fig. 3(a). To confirm the NO_2 selectivity of 2D WS$_2$ nanoflakes, we also measured the gas response toward other gases including NH_3, C_2H_5OH, C_3H_6O, and H_2. As shown in Fig. 3(b), the NO_2 response of 2D WS$_2$ nanoflakes is at least 2 times higher than those of other gases. Therefore, it is reasonable to claim that the 2D WS$_2$ nanoflakes are promising candidate to apply to actual NO_2 sensors.

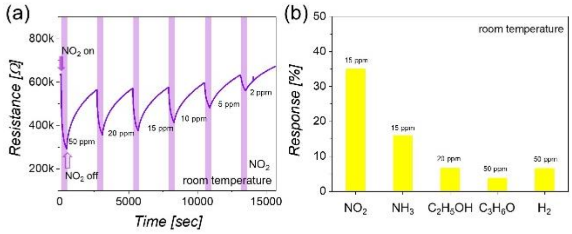

Fig. 3. NO_2 sensing results of 2D WS$_2$ nanoflakes

Interestingly, even though the exfoliated 2D WS$_2$ nanoflakes showed better gas response than CVD-grown 2D WS$_2$ nanoflakes, the difference in gas responses was not obtained. In other words, the exfoliated 2D WS$_2$ nanoflakes did not show the gas selectivity.

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