Medical / Healthcare, Environment monitoring, Smart devices

Development of photoactivated gas sensor using two-dimensional semiconducting materials

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Abstract

Two-dimensional semiconducting materials, such as transition metal dichalcogenides (TMDCs) are promising sensing materials for gas sensors, because their electrical properties are sensitive to the adsorption of gas molecules due to their high surface-to-volume ratio. On the other hand, the TMDCs are also known to have a strong interaction with light, having a high optical absorption coefficient in the visible region, about 10 times higher than that of bulk semiconductors such as silicon and germanium. In this study, we focused on molybdenum disulfide (MoS_2), a kind of the TMDC, and investigated the effect of light illumination on the response of a FET type sensor based on the MoS_2 monolayers to NO_2 gas. We revealed that visible light illumination with a photon energy higher than the bandgap (1.8 eV) of the MoS_2 monolayer significantly improves the sensitivity and response/recovery characteristics.

Background & Results

With the recent development of Internet of Things (IoT) technology, the importance of gas sensors is increasing. Gas sensors for IoT application need to be small, low cost, and have low power consumption, in addition to high sensitivity, high reliability, and high selectivity. Semiconductor gas sensors are promising candidates for IoT sensors because of their small size, low cost, and relatively high sensitivity, but they have the drawback of high-power consumption due to the need for high temperature operation. Therefore, sensor activation by light illumination is attracting attention as an alternative to activation by heat. Conventionally, ultraviolet light, which is harmful to the human body, has been used for the photoactivation. In this study, we found that the sensor response can be efficiently activated at room temperature even by visible light in sensors based on the MoS_2 monolayers as the sensing material.

Figure 1 shows the schematic and microscopic image of the monolayer MoS_2-FET sensor, and the photograph of the setup for sensor measurement. Figures 2a and 2b show the dynamic response of the sensor to 50 ppb NO_2 measured under light illumination with an irradiance of 86 mW/cm^2 and dark conditions. NO_2 is difficult to desorb at room temperature because of its high adsorption energy, therefore the current hardly recovers by gas purging in the dark condition. In contrast, under light illumination, the current fully recovered in a short time by gas purging. Both the response and recovery speeds of the sensor tended to increase as the irradiance increased, which implies that the photo-generated electrons and holes in MoS_2 promote the adsorption and desorption of gas molecules, respectively (see Figure 2c).

The sensitivity and the limit of detection of the sensor were estimated to be 8.6%/ppb and 0.15 ppb, respectively. These sensor performance metrics meet the requirements of the environmental quality standard in Japan (0.04—0.06 ppm as the daily average for hourly values), indicating that this sensor can be used for monitoring air pollution gas.

Significance of the research and Future perspective

The significance of this research lies in the fact that the response characteristics of the sensor can be tuned by adding a third element, light, to the interaction between the two-dimensional semiconducting material and gas molecules. Since light illumination provides excellent sensor performance even at room temperature, it is expected to be developed into ultra-low power consumption gas sensors required for IoT sensors by combining it with energy-efficient micro light sources such as micro-LEDs. Furthermore, by selecting wavelength and modulating intensity of the illumination light, it may be possible to achieve the advanced molecular recognition required for the detection of biological gas species.

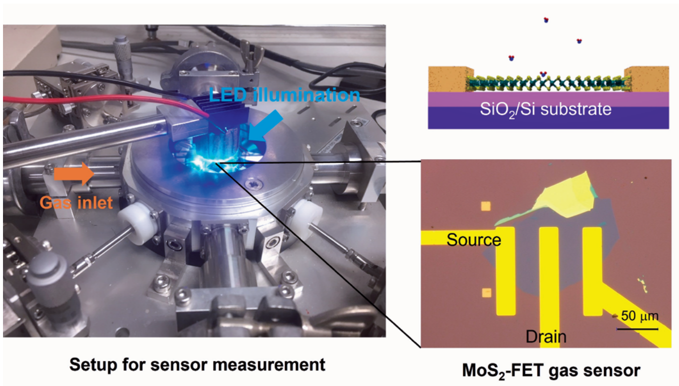

Figure 1

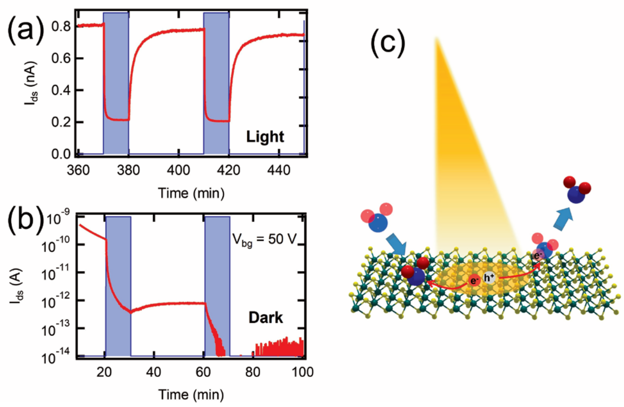

Figure 2

Patent

Treatise: Tabata, Hiroshi; Matsuyama, Hiroaki; Goto, Taishi et al. Visible-Light-Activated Response Originating from Carrier-Mobility Modulation of NO_2 Gas Sensors Based on MoS_2 Monolayers. ACS Nano. 2021; 15(2): 2542-2553. doi: 10.1021/acsnano.0c06996

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