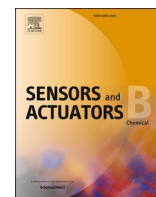




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## Sensors and Actuators: B. Chemical

journal homepage: [www.elsevier.com/locate/snb](http://www.elsevier.com/locate/snb)Insight into mechanism of temperature-dependent limit of NO<sub>2</sub> detection using monolayer MoS<sub>2</sub>Tri Khoa Nguyen<sup>a,b</sup>, Sangmin Jeong<sup>a</sup>, Jong-Sang Youn<sup>c</sup>, Seungbae Ahn<sup>d</sup>, Ki-Hun Nam<sup>e,f</sup>, Cheol-Min Park<sup>e,f,\*</sup>, Ki-Joon Jeon<sup>a,g,\*</sup><sup>a</sup> Department of Environmental Engineering, Inha University, Incheon, 22212, Republic of Korea<sup>b</sup> NTT Hi-Tech Institute, Nguyen Tat Thanh University, 298-300A Nguyen Tat Thanh Street, Ho Chi Minh City, Viet Nam<sup>c</sup> Department of Environmental Engineering, The Catholic University of Korea, 43 Jibong-ro Bucheon-si, Gyeonggi-do, Republic of Korea<sup>d</sup> Department of Nanoengineering, Center for Memory and Recording Research, Calithea Center for Resilient Materials and Systems, University of California San Diego, 9500 Gilman Drive, La Jolla, CA, 92093, USA<sup>e</sup> School of Materials Science and Engineering, Kumoh National Institute of Technology, 61 Daehak-ro, Gumi, Gyeongbuk, 39177, Republic of Korea<sup>f</sup> Department of Energy Engineering Convergence, Kumoh National Institute of Technology, 61 Daehak-ro, Gumi, Gyeongbuk, 39177, Republic of Korea<sup>g</sup> Program in Environmental and Polymer Engineering, Inha University, Incheon, 22212, Republic of Korea

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## ABSTRACT

Recently, many literatures report on the excellent performance of MoS<sub>2</sub>-based NO<sub>2</sub> sensing, however, lacking the study on its thermal stability. Here, the insight mechanism in NO<sub>2</sub> sensor reactivity of monolayer MoS<sub>2</sub> at different temperatures from 25 to 200 °C was investigated. The relative effect of the morphological properties of the sensor and gas sensor reactivity at different temperatures was observed using in situ Raman mapping, optical microscope, and scanning electron microscope to demonstrate the mechanism of temperature-dependent limit of NO<sub>2</sub> detection in ppb. By increasing the temperature from 25 to 100 °C, the response of the sensor significantly improves (4.8 % vs. 54.4 %) at 200 ppb, and its limit of NO<sub>2</sub> detection strongly decreases (48.0 vs. 6.9 ppb). Interestingly, the sensor performance from 100 to 150 °C is likely equivalent to a limit of detection (LoD) that varies from 8.1 to 6.9 ppb, and the LoD slightly increases to 15.0 ppb at 200 °C. The line damages were found in monolayer MoS<sub>2</sub> basal plane by heating the sample up to 200 °C, that affect to the recovery of the NO<sub>2</sub> sensor. This study reveals an effective approach that may be useful in developing a gas sensor with a high response and limit of NO<sub>2</sub> detection in the ppb scale.

## 1. Introduction

The development of industrial processes, vehicles, and power plants is necessary in the era of modern industry; however, this leads to the increase in toxic gas emissions [1]. NO<sub>2</sub> is a typical toxic gas that strongly affects human respiratory systems and the environment [2]. Monitoring the air quality index is important for air pollution control. Therefore, the fabrication of NO<sub>2</sub> sensors with a low limit of detection, high selectivity, and fast response/recovery time is essential. In recent years, NO<sub>2</sub> sensors based on two-dimensional (2D) materials have been studied owing to their high surface to volume ratio, which results in their highly sensitive electrical response to their surface atmosphere

[3–8]. Among various 2D materials, graphene has exhibited excellent gas sensing performance with a high response [9–11]. However, the excellent sensing properties of graphene for many types of gases renders it a low-selectivity sensing material [12]. Monolayer MoS<sub>2</sub> has been considered as a promising alternative to graphene and conventional metal-oxide sensing materials because of its high selectivity for NO<sub>2</sub> and soft-heated operation [13–16]. The key factor in improving NO<sub>2</sub> sensing response is the enhancement of the number of generated surface free electrons on the MoS<sub>2</sub> basal plane, which react with the NO<sub>2</sub> gas. In recent years, studies on the photo-induced gas sensing performance of MoS<sub>2</sub> at room temperature have been widely published [13,17–19]. However, the developed MoS<sub>2</sub> devices require light emitting diodes or

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