

High-Sensitivity and Reliable Gas Sensor by Hybridizing Laser-Induced Graphene and Molybdenum Trioxide with Metal-Organic Decomposition

Akihiro Katsura¹, Otoy Okanishi¹, Yukiko Hirose¹, Yuma Miura¹, Wenliang Zhu¹, Tohru Sugahara¹
¹ *Kyoto Institute of Technology, Matsugasaki, Sakyo-ku, Kyoto, 606-8585, Japan*
katsura.akihiro.1025@gmail.com

Summary:

Volatile organic compounds are attracting increasing attention in health monitoring, environmental assessment, and industrial process control. Therefore, simple strategies for developing gas sensors with high sensitivity and rapid response are strongly desired. In this work, laser-induced graphene is employed as a conductive scaffold and molybdenum trioxide as a gas-reactive material to construct a hybrid sensing platform through metal-organic decomposition. This approach provides a simple route to hybrid sensing materials for high-performance volatile organic compound sensing.

Keywords: Laser-Induced Graphene, Molybdenum Trioxide, Metal-Organic Decomposition, Gas Sensor, Volatile Organic Compounds

Introduction

Volatile organic compounds are attracting increasing attention in health monitoring, environmental assessment, and industrial process control. In particular, methanol, ethanol, 1-propanol, and 2-propanol have been investigated as representative volatile organic compounds related to metabolic disorders, alcohol consumption, bacterial infections, and diabetic ketoacidosis, respectively [1-2]. Therefore, gas sensors with high sensitivity, rapid response, and stable operation are strongly desired for practical volatile organic compound monitoring. Metal oxide semiconductors have been widely studied as gas sensing materials because of their high sensitivity and rapid response originating from surface redox reactions [3]. However, their low carrier mobility and high electrical resistivity often impose a substantial electrical burden on sensor devices. Hybridization with conductive carbon materials has recently attracted attention as an effective way to address these drawbacks and enhance sensing performance [4]. In particular, laser-induced graphene offers high electrical conductivity, large surface area, and simple fabrication directly on polymer substrates, making it an attractive platform for hybrid gas sensors [5]. However, a facile strategy for integrating highly crystalline gas-reactive metal oxides with laser-induced graphene has not been sufficiently established. In this study, laser-induced graphene was employed as a conductive scaffold and molybdenum trioxide as a gas-reactive material, and a metal-organic decomposition strategy was

adopted to integrate both components into a hybrid sensing platform for volatile organic compound detection.

Experimental

Laser-induced graphene was fabricated on polyimide films by direct laser irradiation using a YVO₄ laser marker. For hybridization, a precursor solution containing ammonium molybdate, citric acid, and N,N-dimethylformamide was deposited onto the laser-induced graphene by spin coating, followed by sintering in air at 673 K for 15, 30, and 60 min to form molybdenum oxide. The resulting structures were analyzed by field-emission scanning electron microscopy, X-ray diffraction, X-ray photoelectron spectroscopy, and Raman spectroscopy to evaluate their morphology, crystal structure, and chemical states. Gas sensing performance was evaluated by monitoring resistance changes toward methanol, ethanol, 1-propanol, and 2-propanol under heated conditions.

Results and Discussion

Fig. 1(a) shows the surface morphology of laser-induced graphene optimized as a conductive platform for gas sensing. The laser-induced graphene exhibited a wave-like porous network structure, which is favorable for providing both continuous electrical conduction pathways and a large specific surface area. Fig. 1(b) shows the surface morphology of the LIG/ α -MoO₃ hybrid material after the synthesis using metal-organic

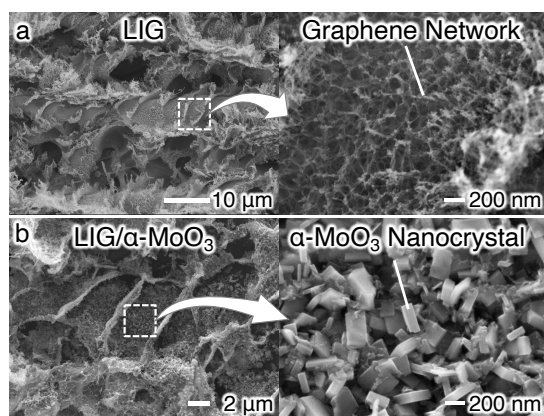


Fig. 1. Surface morphology of (a) laser-induced graphene (LIG). (b) LIG/ α - MoO_3 hybrid materials.

decomposition. Nanostructured α - MoO_3 was densely formed on the graphene network while the underlying laser-induced graphene framework was preserved, indicating that the metal-organic decomposition process successfully hybridized the gas-reactive oxide with the conductive scaffold without severe degradation of the carbon structure. This hybrid structure is expected to combine efficient charge transport through laser-induced graphene with abundant gas-reaction sites from α - MoO_3 . Fig. 2(a) shows the sensing properties of LIG/ α - MoO_3 toward various volatile organic compounds at approximately 350 ppm. The hybrid sensor responded to all tested gases, including methanol, ethanol, 1-propanol, and 2-propanol, and the response strongly depended on the gas species. In particular, methanol showed the largest response, followed by 1-propanol, 2-propanol, and ethanol, demonstrating selective discrimination among alcohol-based volatile organic compounds. Fig. 2(b) shows the repeatability of the sensor response to 44.7 ppm methanol under repeated injection cycles. A stable cyclic response was observed with a coefficient of variation of 3.62%, indicating good repeatability at low concentration. These results demonstrate that the hybridization of laser-induced graphene and α - MoO_3 effectively improved volatile organic compound sensing by combining conductive charge transport with dense gas-reactive nanostructures.

Conclusion

In this study, laser-induced graphene and α - MoO_3 were integrated by metal-organic decomposition to construct a hybrid gas-sensing platform. The resulting hybrid showed clear responses toward volatile organic compounds, with the highest response and stable repeatability toward methanol. These results demonstrate that metal-organic decomposition is a simple and effective strategy for fabricating high-performance hybrid gas sensors.

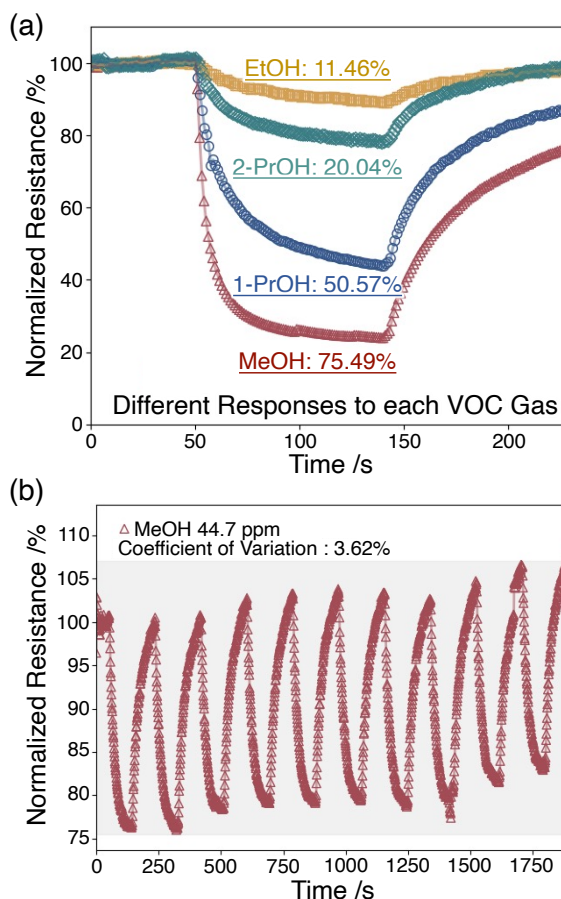


Fig. 2. (a) Sensing properties of LIG/ α - MoO_3 hybrid gas sensor toward volatile organic compounds gases. (b) Repeatability of the sensor responses toward 44.7 ppm methanol.

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