

Enhancement of Receptor Function on Metal Oxide Semiconductor Gas Sensors for Ultra Selectivity

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Summary:

In this study, we investigated the combination of receptor function, one of the material design guidelines for semiconductor gas sensors, and the gas adsorption characteristics during MEMS driving, along with the reaction with adsorbed oxygen during heating, to achieve ultra-high selectivity. Specifically, by using MoO₃-loaded SnO₂ particles as the sensing film of MEMS gas sensors and applying double-pulse driving, we found a significant improvement in ethanol sensitivity compared to methanol.

Keywords: semiconductor gas sensor, receptor function, selectivity, acidic oxides, tin dioxide

Introduction

As guidelines for material design in semiconductor gas sensors, we propose three important factors (Yamazoe-Shimano Design) [1]: receptor function, transducer function, and utility factor. Among these factors, those related to gas selectivity are receptor function and utility factor. Receptor function directly relates to factors such as chemical reactivity and functional group characteristics. We aim to maximize this receptor function to propose gas sensors with ultra-high selectivity. Specifically, tin oxide, which has the ability to adsorb negatively charged oxygen, is used as the base material, while acidic oxides that do not possess the ability to adsorb negatively charged oxygen are loaded as receptors on the base material. In this sensor material, adsorption of the target gas to the receptor and the partial oxidation reaction of the adsorbed gas with negatively charged oxygen proceed, resulting in ultra-high selectivity. In this study, we report the fundamental characteristics using MEMS sensors.

Experimental

SnO₂ nanoparticles were synthesized using hydrothermal treatment using 1 M of SnCl₄·5H₂O solution and NH₄HCO₃ solutions. After removing Cl⁻ ion by centrifugation, the gel was dispersed into deionized water with stirring. Then the pH of mixture was adjusted to 10.5 by tetramethylammonium hydroxide (15 %) solution. Subsequently the mixture was transferred to a Teflon-lined autoclave and held at 200°C for 10 h in an oven. The transparent sol was dried in

vacuum, and then annealed at 600°C for 3 h under O₂ flow to prepare the SnO₂ nanoparticles. As receptors, we selected MoO₃ which is one of acidic oxides. MoO₃-loaded SnO₂ was prepared through impregnation method. The MEMS sensor was fabricated by the micromanipulation method using MoO₃-loaded SnO₂. For MEMS

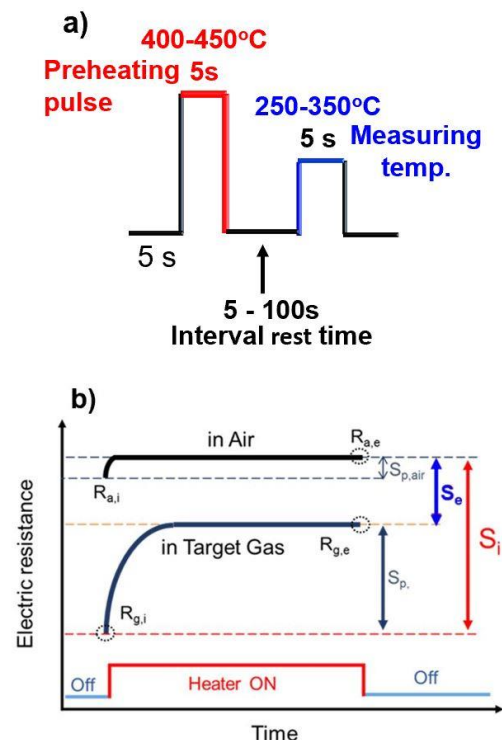


Fig. 1. (a) Operating processes during double-pulse-driven mode; (b) Explanation of the sensor responses.

sensors, the electrical resistance of obtained gas sensors was evaluated using double-pulse-driven mode [2-3], as described in Figure 1. The preheating and measurement temperature was respectively set to 450°C and 350°C. During the detection process, the electrical resistance of sensor could be divided to R_a (the resistance in air), $R_{g,i}$ (the resistance in gas at the initial of measurement phase), and $R_{g,e}$ (the resistance in gas at the end of measurement phase). On the basis, we proposed three different sensor responses, S_e ($R_a/R_{g,e}$), S_p ($R_{g,e}/R_{g,i}$), and S_i ($R_a/R_{g,i}$).

Results

Fig. 2a)-b) shows sensor responses S_p , S_i and S_e of neat-SnO₂ and MoO₃-loaded SnO₂ microsensors to 10 ppm ethanol and methanol measured at 350°C under double-pulse-driven (DP) mode. Herein, S_p ($R_{g,e}/R_{g,i}$) primarily represented the combustion of adsorbed and condensed gas molecules during measuring period. And S_i ($R_a/R_{g,i}$) referred to the total resistance change between air and target gas atmosphere, including gas adsorption and combustion in the sensing layer. It was clear that neat-SnO₂ exhibited an extremely minimal S_p of about 3, demonstrating the weak combustion of adsorbed ethanol molecules in the sensing layer of SnO₂. Meanwhile, S_p of MoO₃-loaded SnO₂ to 10 ppm ethanol was approximately 496. Generally, the sensing performance of resistive-type gas sensor was evaluated by the change in electrical resistance between air and gas atmosphere. The improved S_p value indicated it is possible to accomplish gas detection only by monitoring the behavior of microsensor in gas atmosphere. Moreover, S_i values showed similar results with S_p , MoO₃-loaded SnO₂ exhibited distinctly higher response to ethanol than neat-SnO₂ microsensor. The sensor responses (S_e) of neat-SnO₂ and MoO₃-loaded SnO₂ microsensors to 10 ppm ethanol and methanol at 350°C are shown in Fig. 2c). Conversely, the MoO₃-loaded SnO₂ microsensor exhibited much lower S_e values for both ethanol and methanol compared to the neat-SnO₂ microsensor.

The results prove the significant effect of receptor material design on improving the gas sensing performance by controlling the reaction pathway and gas adsorption.

References

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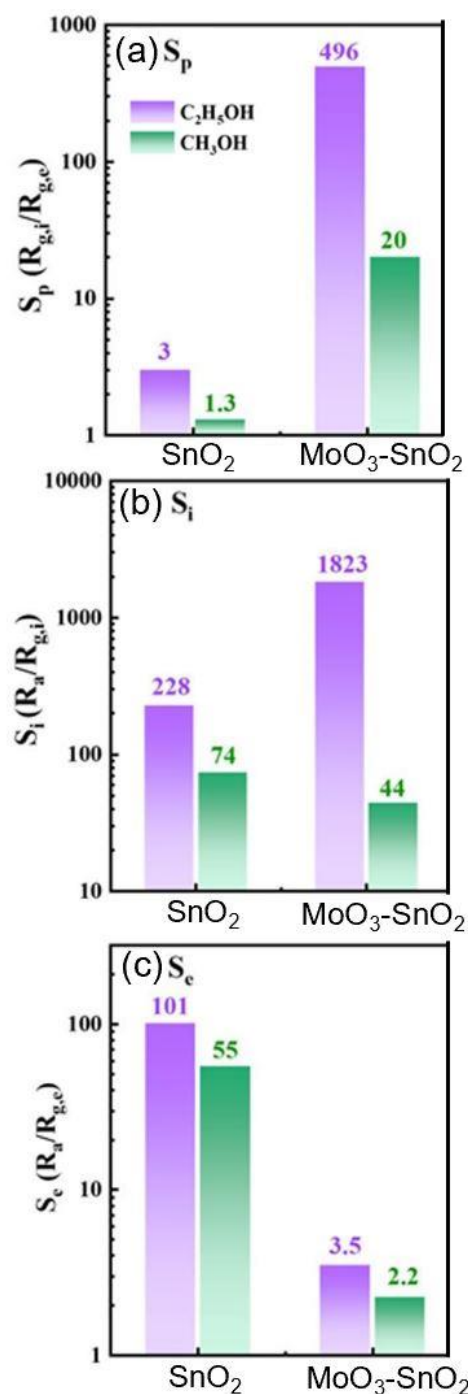


Fig. 2. (a) S_p , (b) S_i and (c) S_e values of neat-SnO₂ and MoO₃-loaded SnO₂ microsensors to 10 ppm ethanol and methanol under DP-mode.

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