Low-Temperature Operating SnO_2 Nanowire NO_2 Sensor

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Abstract

The network structure of SnO_2 nanowires was fabricated on the electrodes by a simple thermal evaporation process from Sn metal powders and oxygen gas. The diameter of the nanowires was 20 ~ 60 nm depending on the processing conditions. The operating temperature of the sensor could be decreased down below 50°C by controlling the properties of the nanowires and the structures of the electrodes. The sensitivities were 10 ~ 15 when the NO_2 concentrations were 10 ~ 50 ppm at the operating temperature of 50°C.

I. Introduction

In recent years, semiconducting nanowires and nanorods have attracted considerable interests for their potential use in various nanoscale devices using the integrity of the individual nanowires and nanorods [1]. Among them, SnO_2, an n-type semiconductor with a large band gap (E_g = 3.6 eV at 300K) showed interesting features in the aspects of the synthesis and the device applications.

In this work, a simple and efficient way of producing SnO_2 nanowire-based NO_2 sensors of high sensitivity with fast response, without an arduous and individual lithography process, was studied. In particular, the operating temperature of the sensor could be decreased down below 50°C by controlling the properties of the nanowires and the structures of the electrodes.

II. Experimental

Firstly, for the fabrication of sensor devices, electrodes were defined on the Si substrate by a conventional photolithography process, as shown in Fig. 1 (a). The size of the electrodes were 3 * 3 mm and the gap between the electrodes was 10 ~ 30um. The Pt (5000 Å) and Ti (500Å) layer were deposited on the Si substrate in sequence by an e-beam, sputtering. The Au (200Å) catalyst layer was sputtered by a thermal evaporation process. Upon the defined electrodes, SnO_2 nanowires were synthesized by a thermal CVD process from the Sn metal and the oxygen gas [2].

Fig. 1 (b) shows a typical example of SnO_2 nanowires cross-connected between two electrodes.

Ⅲ. Results and Discussion

Fig. 2 shows the NO_2 sensing characteristics of the SnO_2 nanowire gas sensor. The gas sensitivity is defined as R_g/R_a, where R_a is the electrical resistance in air and R_g is the resistance in NO_2 gas. The response and the recovery time is defined as the 90% of the time required to reach the maximum R_g and the minimum R_a, respectively. At the operating temperature of 200°C, the sensitivity of 40 ~ 60 could be obtained when the NO_2 gas concentration was 10 ~ 20ppm. The highest sensitivity of 60 was obtained when 20 ppm of NO_2 is injected. In the Fig. 2 (a), the response and the recovery time were 38 s and 25 s, respectively. The reaction time was noticeably faster than any other bulk and thin film type SnO_2 sensors. It is believed that the presented structure of the gas sensor in this work has an advantage in terms of the adsorption and desorption of gas molecules. According to the literature [3], the response time to detect the target gas strongly depends on the degree of diffusion of the gas molecules into the sensor. As the SnO_2 nanowires in this study are sufficiently randomly oriented to generate a highly porous structure, they can exhibit quite faster reaction time.

It is noteworthy that the operating temperature of the sensor could be decreased down below 50°C by controlling the structures of the nanowires and the electrodes. The sensitivities were 10 ~ 15 when the NO_2 concentrations were 10 ~ 50 ppm at the operating temperature of 50°C.

Table. 1 summarizes all the sensitivity, response time, and recovery time of a sample. At the temperatures below 100°C, the sensitivities were 10 ~ 20 were obtained. However, the response time and recovery time increases significantly as the operating temperature decreases, which could be explained lower reaction rate of the NO_2 gas species on the surface of the nanowires.

References

[1] X. F. Duan, Y. Huang, Y, Cui, J. Wang and C. M. Lieber, Nature 409, 66 (2001).

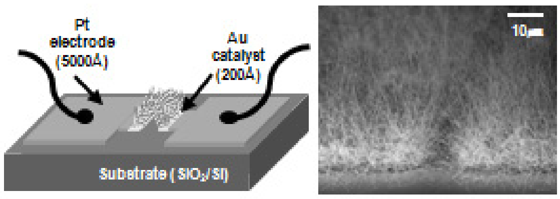
[2] Z. Pan, Z. Dai and Z. L. Wang, Science 291, 1947 (2001).

[3] N. Barsan and U. Weimar, J. Electroceram. 7,143 (2001).

Table. 1 A summary of the sensitivity, response time, and recovery time of a sample with different NO_2 concentrations and the working temperatures.

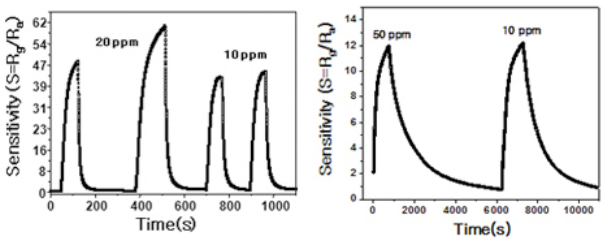
	Sensitivity($S=R_g/R_a$)			Response time(s), 90%			Recovery time(s), 90%		
	10ppm	50ppm	100ppm	10ppm	50ppm	100ppm	10ppm	50ppm	100ppm
200℃	43	-	-	38	-	-	25	-	-
100℃	11	13	17	170	34	34	160	130	80
50℃	12	10	4.5	590	510	140	1850	2170	450

Figure Captions.



(a) (b)

Fig. 1 (a) A schematic illustration of the gas sensor device. (b) A SEM image of the synthesized SnO_2 nanowires between the electrodes.



(a) (b)

Fig. 2 NO_2 gas sensing characteristics of the SnO_2 nanowires with different NO_2 concentrations at the working temperatures of (a) 200℃ (b) 50℃.