Low-Temperature Operating SnO₂ Nanowire NO₂ Sensor

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Abstract

The network structure of SnO₂ 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 NO₂ 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, SnO₂, an n-type semiconductor with a large band gap (Eₗ = 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 SnO₂ nanowire-based NO₂ sensors of high sensitivity with fast response, without an arduous and individual photolithography 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 ~ 30μm. The Pt (5000 Å) and Ti (500 Å) layer were deposited on the Si substrate in sequence by an e-beam, sputtering. The Au (200 Å) catalyst layer was sputtered by a thermal evaporation process. Upon the defined electrodes, SnO₂ 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 SnO₂ 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 with different NO$_2$ concentrations and the working temperatures.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Sensitivity ($S=R_g/R_a$)</th>
<th>Response time(s), 90%</th>
<th>Recovery time(s), 90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>200°C</td>
<td>43</td>
<td>10ppm</td>
<td>10ppm</td>
</tr>
<tr>
<td>100°C</td>
<td>11</td>
<td>50ppm</td>
<td>50ppm</td>
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<tr>
<td>50°C</td>
<td>12</td>
<td>100ppm</td>
<td>100ppm</td>
</tr>
</tbody>
</table>

Figure Captions.

Fig. 1 (a) A schematic illustration of the gas sensor device. (b) A SEM image of the synthesized SnO$_2$ nanowires between the electrodes.

Fig. 2 NO$_2$ gas sensing characteristics of the SnO$_2$ nanowires with different NO$_2$ concentrations at the working temperatures of (a) 200°C (b) 50°C.

References