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Fabrication of SnO_2 Nanotube Arrays for Enhanced Gas Sensing Properties

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Abstract : Metal-oxide semiconductor (MOS) gas sensors are widely used in the gas-detection market due to their high sensitivity, fast response, and simple device structures. However, the high working temperature of MOS gas sensors makes them difficult to integrate with the appliance or consumer goods. One-dimensional (1-D) nanostructures are considered to have the potential to lower their working temperature due to their large surface-to-volume ratio, confined electrical conduction channels, and small feature sizes. Unfortunately, the difficulty of fabricating 1-D nanostructure electrodes has hindered the development of low-temperature MOS gas sensors. In this work, we proposed a method to fabricate nanotube-arrays, and the SnO_2 nanotube-array sensors with different wall thickness were successfully prepared and examined. The fabrication of SnO_2 nanotube arrays incorporates the techniques of barrier-free anodic aluminum oxide (AAO) template and atomic layer deposition (ALD) of SnO_2. First, 1.0 µm Al film was deposited on ITO glass substrate by electron beam evaporation and then anodically oxidized by five wt% phosphoric acid solution at 5°C under a constant voltage of 100 V to form porous aluminum oxide. As the Al film was fully oxidized, a 15 min over anodization and a 30 min post chemical dissolution were used to remove the barrier oxide at the bottom end of pores to generate a barrier-free AAO template. The ALD using reactants of TiCl4 and H_2O was followed to grow a thin layer of SnO_2 on the template to form SnO_2 nanotube arrays. After removing the surface layer of SnO_2 by H_2 plasma and dissolving the template by 5 wt% phosphoric acid solution at 50°C, upright standing SnO_2 nanotube arrays on ITO glass were produced. Finally, Ag top electrode with line width of 5 µm was printed on the nanotube arrays to form SnO_2 nanotube-array sensor. Two SnO_2 nanotube-arrays with wall thickness of 30 and 60 nm were produced in this experiment for the evaluation of gas sensing ability. The flat SnO_2 films with thickness of 30 and 60 nm were also examined for comparison. The results show that the properties of ALD SnO_2 films were related to the deposition temperature. The films grown at 350°C had a low electrical resistivity of 3.6×10-3 Ω-cm and were, therefore, used for the nanotube-array sensors. The carrier concentration and mobility of the SnO_2 films were characterized by Ecopia HMS-3000 Hall-effect measurement system and were 1.1×1020 cm-3 and 16 cm3/V-s, respectively. The electrical resistance of SnO_2 film and nanotube-array sensors in air and in a 5% H_2-95% N_2 mixture gas was monitored by Pico text M3510A 6 1/2 Digits Multimeter. It was found that, at 200 °C, the 30-nm-wall SnO_2 nanotube-array sensor performs the highest responsivity to 5% H_2, followed by the 30-nm SnO_2 film sensor, the 60-nm SnO_2 film sensor, and the 60-nm-wall SnO_2 nanotube-array sensor. However, at temperatures below 100°C, all the samples were insensitive to the 5% H_2 gas. Further investigation on the sensors with thinner SnO_2 is necessary for improving the sensing ability at temperatures below 100 °C.

Keywords : atomic layer deposition, nanotube arrays, gas sensor, tin dioxide
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