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Porous single-wall carbon nanotube films formed by *in Situ* arc-discharge deposition for gas sensors application

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ABSTRACT

A gas sensor structure for high performance is developed based on a porous film structure of single-wall carbon nanotubes (SWNTs). The SWNTs are directly deposited on the substrate *in situ* in the arc-discharge chamber, and the steric hindrance during the deposition permits high porosity in the carbon nanotube thin film. The SWNTs are characterized and their capacities of sensing NO and NH_3 gases are investigated down to 2 ppm-level concentration at room and elevated temperatures. The effect of sensor porosity is examined and compared with that of a nonporous sensor structure. The response and recovery behaviors are examined with temperature variations.

1. Introduction

Many of the gas sensors that are made of semiconducting oxide materials such as SnO_2, TiO_2, In_2O_3, and ZnO are based on the changes in electrical resistance of the materials upon gas adsorption [1,2]. In the sensor structures, the principle naturally requires a larger surface-area-to-volume ratio for high sensitivity; for this matter, thin films and porous thick films have been extensively studied. Recently, nanostructures, such as carbon nanotubes (CNTs), with extremely high surface-area-to-volume ratios, have begun attracting wide attention in the study of their application to various sensors. So far, CNT-based gas sensors have been investigated for the detection of H_2, N_2, NO_2, and NH_3, among others [3–13]. Both single-wall carbon nanotubes (SWNTs) [3–7] and multiwall carbon nanotubes (MWNTs) [8–13] have been tested as sensing probes.

In principle, a single wire of CNT can form a sensor and provide important intrinsic sensing properties when used as a sensing material. However, until the technology to regularly array the single wires is developed, it is an inappropriate unit of engineering device for mass production. Therefore, the realistic engineering sensor at present should be made of a thin film form of CNTs. In the film type CNT sensors, not only the intrinsic CNT properties, but also the extrinsic conditions can affect final sensor performance. Examples of these external conditions are film thickness, density, and porosity in relation to gas permeability, the CNT alignment (parallel and vertical), and entanglement in relation to the CNT-to-CNT contacts that determine the current paths, impurity materials and distribution, among others.

If we review the thin film type CNT gas sensor structures, they are mostly either pasted CNTs [5,6] or CVD-grown CNTs [11,13–15]. The method of pasting CNT is a direct and easy way of film formation, but requires sequential processing of synthesis and collection of CNTs, as well as dispersion in solutions or polymer, and printing on substrates [4,16]. In addition to the above-mentioned complexity of the process, controlling the thinness of the CNTs for better performance of the sensor device is a great challenge. When the films are thick, the sensitivity of the sensor decreases because the buried part in the film will not act as the probe. This will also be the case for the composite blended with polymer. On the other hand, in the self-assembled CNT film case, most of the MWNTs are grown vertically by the CVD method using catalyst metals [11,13,14] and the electrodes are patterned parallel to the plane. Therefore, the current paths are formed through contacts among the vertical CNTs. One can easily recognize that this geometry does not efficiently deliver the signal changes to the electrodes. The efficiency and the sensitivity will be improved if the CNTs are grown laterally between the electrodes [15]. For efficiency in mass production, however, this method should be developed to control the areal density of the CNTs.

Therefore, in this study, the authors report the development of a CNT sensor structure with a potential for ultimate sensitiv-

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