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Dielectrophoretic Synthesis and Characterization of Nanomaterial-Based Sensors

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ABSTRACT

This research will examine synthesis of single-wall carbon nanohorns (SWCNHs) by dielectrophoresis (DEP). This will involve electrokinetic synthesis method which will produce a SWCNHs sensor. In dielectrophoresis (DEP), the carbon particles will be subjected to a non-uniform electric field and thus a force will be exerted on the particles. The materials are dielectrically polarized with electrokinetic motion in non-uniform electric fields. The region of higher electric field will attract the nanoparticles due to positive DEP force. The carbon nanoparticles are then trapped in the electrode gap and thus form an electrical connection to the external measuring circuit. This method provides a fast, simple and low cost fabrication of nanomaterial-based sensors based on a bottom-up approach.

1. Introduction

A lot of interest in carbon nanomaterials has grown tremendously since the discovery of carbon nanotubes. As a result research in carbon nanomaterials has led to the discovery of single-wall carbon nanohorn (SWCNHs). One of the advantage of SWCNHs is since there is no metal catalyst which is required for their synthesis they are free from contamination by metallic impurities. They have a large surface area and a high gas absorption capacity hence they are ideal for gas storage or fuel cell applications. In dielectrophoresis (DEP) the polarized material is attracted toward or repelled away from the high field region depending on the complex dielectric permittivity of the particle and its surrounding medium (Pethig R., 2007). The research demonstrates that the DEP manipulation provides a way to trap and retain carbon nanohorns (Suehiro J., Hidaka S., Yamane S., and Imasaka K., 2007) on metallic microelectrodes and that these DEP-trapped nanomaterials serve as sensing elements. One advantage of the DEP fabrication technique is that one can quantify the amount of trapped nanomaterials on a real-time basis by monitoring electrical impedance of the sensor dielectrophoretic impedance measurement (DEPIM) (Suehiro J., Yatsunami R., Hamada R., and Hara M., 1999). This feature enables one to precisely control and calibrate the response of the nanomaterial-based sensors. Another advantage is that various combinations of nanomaterials and metallic microelectrodes can be obtained because two processes of nanomaterial synthesis and sensor fabrication are separated (Bianco A., Kostarelos K., and Prato M, 2005).

2. Methodology

Fig 1 shows a DEP-based fabrication system for the nanomaterial-based sensor which is based on dielectrophoretic impedance measurement (DEPIM) system. The SWCNH powders were suspended in ethanol. An interdigitated microelectrode of thin chrome film (100 nm thickness) is patterned on a glass substrate (20 mm × 20 mm) by the photolithography technique. The electrode finger had a castle-wall pattern (5 mm length and 5 µm minimum clearances) in order to form high and low electric field regions periodically. The castellations are squares with sides of 50 µm. The 20 electrode fingers formed 19 castellated gaps. The castle-wall electrodes were surrounded by a silicon rubber spacer to form a sealed chamber (15 µl capacity), in which the SWCNH suspension was stored. The DEP trapping of nanomaterials on the microelectrode was performed with an ac voltage of 8V peak-to-peak amplitude and 100 kHz frequency for the while SWCNHs suspension continuously flowed through the chamber at 0.5 ml/min. This ac voltage was also used to simultaneously measure the electrode impedance so that the amount of DEP-trapped nanomaterial was quantified using a lock-in amplifier and controlled by a personal computer, which also served as a data recorder analyzer (Suehiro J., Zhou G., Imakiire H., Ding W., and Hara M., 2005). After the DEP process the aqueous medium was gently evaporated at room temperature so the microelectrode structure which retained worked as a gas sensor.

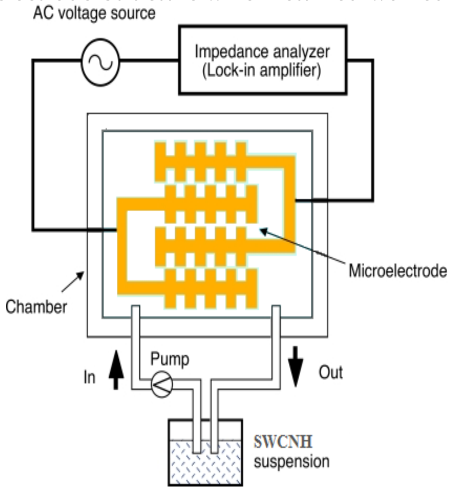

Fig.1. DEP-based fabrication system for nanomaterial-based sensor

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The sensor in this paper has a simple basic structure composed of a DEP-trapped nanomaterial and a metallic microelectrode. The nanomaterial serves as a sensing transducer, while the microelectrode merely provides an electrical connection to the external measurement instrumentations.

3. Results and Discussion

Fig 2 shows a scanning electron microscope (SEM) image of SWCHs which were trapped on the chrome microelectrode. SWCNHs were trapped around the electrode corner, where the electric field became higher indicating that positive DEP is dominant for the SWCNH trap (Suehiro J., Zhou G., and Hara M., 2003). Since the SWCNHs were longer than the electrode gap, the trapped SWCNHs bridged the gap and established electrical connection between the electrodes. The SEM image also revealed that DEP-trapped SWCNHs could be firmly immobilized on the microelectrode even after the evaporation of aqueous suspension. The immobilization might be attributed to strong van der Waals interactions between the SWCNHs and electrode surface (Seo H. W., Han C. -S., Hwang S. O., and Park J., 2006) and (Lao C. S., Liu J., Gao P., Zhang L., Davidovic D., Tummala R., and Wang Z. L., 2006). During the DEP process, the electrode conductance increased with elapsed time, namely, with more SWCNHs trapped onto the electrode. The conductance increment from the initial value represents the total conductance DEP-trapped SWCNHs. DEPIM provides a way to quantify the amount of nanomaterials on a real-time basis. Fig 3 shows responses of a DEP-fabricated SWCNH gas sensor to NO_2 (oxidative) and NH_3 (reducing) gases obtained at room temperature. The electrical conductance of SWCNH sensor increased or decreased upon exposure to ppm-level $NO_2$and NH_3, respectively. The sensor responses were attributed to p-type semiconducting behavior of SWCNH. The initial conductance dependency of the SWCNT sensor response for 1 ppm NO_2 is summarized in Fig.4 (Suehiro J., Imakiire H., Hidaka S., Ding W., Zhou G., Imasaka K., and Hara M., 2006). The initial conductance G0 is the conductance just before NO_2 exposure. The sensor response ΔG increased almost proportionally with G0. This implies that the sensor response normalized by the initial conductance, ΔG/G0, can be a measure for intrinsic sensitivity of the SWCNT gas sensor. The DEP fabrication and impedance monitoring can effectively control the initial conductance of the SWCNH sensor and can improve reproducibility and uniformity of the sensor response (Suehiro J., Sano N., Zhou G., Imakiire H., Imasaka K., and Hara M., J., 2006).

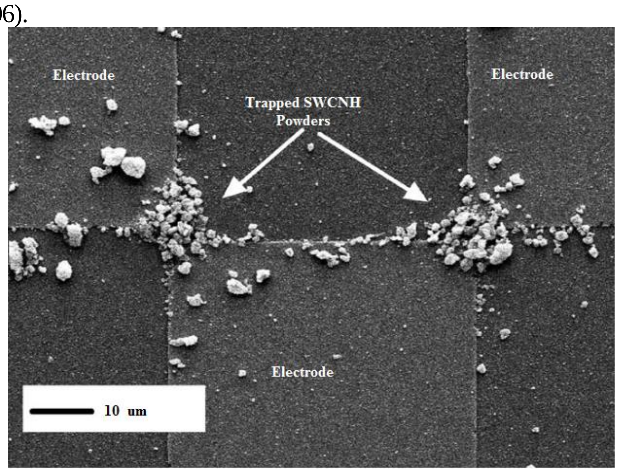

Fig.2.SEM image of the DEP-trapped SWCNH powders in the castellated gap.

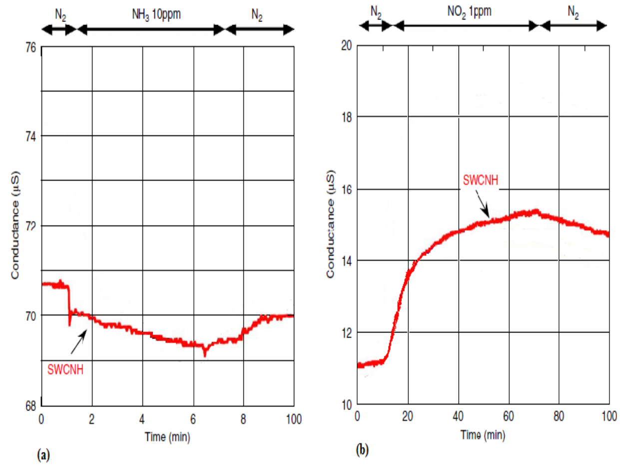

Fig.3. Conductance responses of a DEP-fabricated SWCNH gas sensor measured at room temperature. (a) 10 ppm NH_3 in N_2 gas. (b) 1ppm NO_2 in N_2 gas.

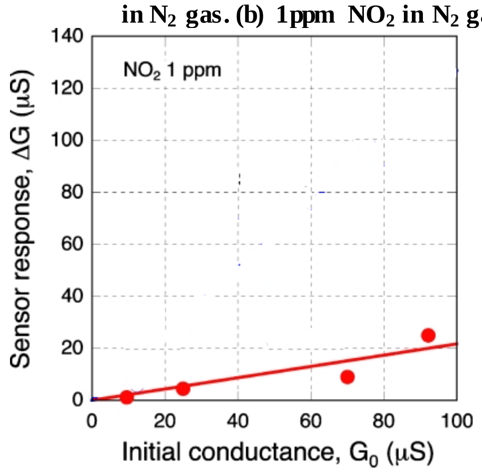

Fig.4. A linear relationship between the initial conductance G0 and SWCNH sensor response ΔG to 1 ppm NO_2 in N_2 gas

4. Conclusions

Electrokinetic synthesis of the SWCNH was depicted using positive dielectrophoresis (DEP) in the ac electric field. The DEP technology has been successfully used to bottom-up fabrication of chemical and physical sensors composed of various nanomaterials. The DEP manipulation can realize a simple, fast, and low-cost assembly of nanomaterial-based sensors, which have many advantages, such as higher sensitivity and wider range of detection capabilities over conventional sensors composed of thin films or bulky material. Since it is difficult to control the location of the SWCNH growth using catalysts, as well as to establish the electrical connection across the electrode gap by random deposition of the SWCNH, the DEP may be a promising technique for the manipulation of SWCNHs during device fabrication.

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