Thick Film of Carbon Nanotube Composite for Ethanol Sensor

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ABSTRACT

One interesting application of carbon nanotubes is their use as a gas sensor. In this work, a thick film carbon nanotube composite was prepared by mixing carbon nanotube powder with iso-butyl methyl ketone and painted onto alumina substrates. Then, the composite's gas-sensing properties for ethanol vapor were tested by measuring the resistance change of the composite at ethanol concentrations of 50, 100, 500, and 1,000 ppm at room temperature. An increase in resistance of 2–5 ohm has been observed with a responsiveness of about 0.01, a sensitivity of about 1 and a response time (τ_{90}) of about 10 sec. The sensing mechanism of the composite could be explained on the basis of volume expansion and polar interaction of various vapors on the carbon nanotube surface.

Key words: Carbon nanotube, Thick film, Composite, Gas sensor

INTRODUCTION

Carbon nanotubes (CNTs) have a wide variety of potential applications including field emission devices, electronic switches, biological sensors, flow sensors and gas storage (Govindaraj and Rao, 2002; Ghosh et al., 2003; Kruger et al., 2003; Philip et al., 2003; Stetter et al., 2003). One potential important application of CNTs is as a gas sensor. Gas sensing properties depend on the surface area and the huge surface area of the nanotubes, because of their hollow cores and outside walls, make them an exceptional candidate material for such applications. (Dai et al., 2002; Ong et al., 2002; Choopun et al., 2004; Lizznersk et al., 2004; Tan, 2004). Several methods such as arc-discharge, laser vaporization, chemical vapor deposition (CVD), pyrolysis and electrolysis (Singjai, 2005) can be used to fabricate CNTs. For gas sensor application, CNT composites have been typically used. The gas sensors based on CNT/polymer, ceramic and metal oxide composites such as epoxy, polyimide, PMMA, BaTiO3 and SnO_2 (Dai et al., 2002; Ong et al., 2002; Philip et al., 2003) have been demonstrated. The gas sensing properties of CNT composites toward various gasses such as dichloromethane, chloroform, acetone, methanol, oxygen, carbon dioxide and ammonia have been reported. For example, Philip and co-workers reported CNT/PMMA composite thin films for gas-sensing application (Philip et al., 2003). They observed an increase of resistance in the order of 10^2–10^3 toward dichloromethane, chloroform and acetone due to surface modification and explained the gas sensing mechanism on the basis of volume expansion and polar interaction of various vapors on the CNTs surface.

In the present paper, we report on the gas-sensing properties of CNTs/iso-butyl methyl ketone composite thick film toward ethanol vapor.

MATERIALS AND METHODS

CNTs in bulk quantity were synthesized by alcohol catalytic chemical vapor deposition(AC-CVD) (Singjai, 2005). The thick films of CNT composite were prepared by mixing CNTs with 75 wt% iso-butyl methyl ketone ($(CH_3)_2.CH.CH_2.COCH_3$) and painted onto alumina substrate. The general morphology of CNT composites was investigated by field emission scanning electron microscope (FE-SEM). After drying in air, CNT composites were painted with silver paint and connected with copper wires to form the interdigital electrodes. The gas sensor based on CNT composite was tested in cylindrical gas flow chamber. The characteristics of sensor were observed from the changing of resistance in air and in ethanol ambient with ethanol concentration of 50, 100, 500 and 1000 ppm and at work temperature of 38–150°C. The response and recovery as a function of time were monitored and recorded via interfaced personal computer.

RESULTS AND DISCUSSION

Figure 1 shows FE-SEM image of the thick film of CNT composites prepared by mixing CNTs with iso-butyl methyl ketone and painted onto an alumina substrate. The general morphology of the composite consists of CNTs with diameters of 50–200 nm.

Work temperatures:

The response and recovery curves of the CNT composite-based sensor at operating temperatures of 38, 50, 100 and 150°C under an ethanol vapor concentration of 1,000 ppm are shown in Figure 2. It is seen that the sensor resistance under the ethanol atmosphere is higher than the resistance in air and that the increase of resistance depends on the operating temperatures. The resistance of the sensor increases as the operating temperature decreases. The largest resistance increase was observed at a temperature of 38°C, suggesting an optimum operating temperature.

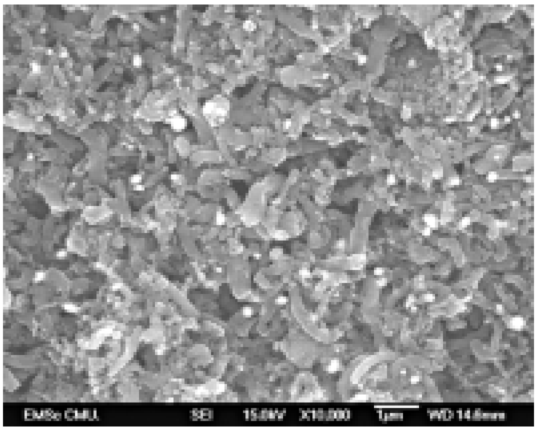

Figure 1. FE-SEM image of the thick film of CNT composites prepared by mixing CNTs with iso-butyl methyl ketone and painted onto alumina substrate.

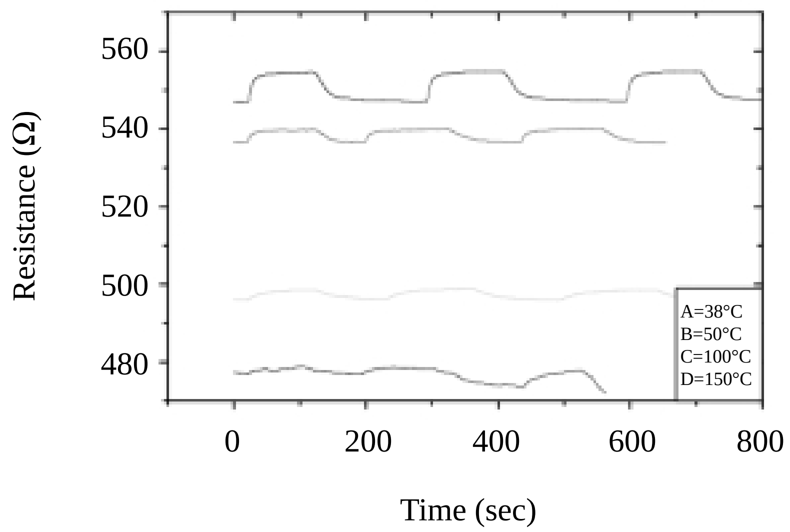

Figure 2. Response and recovery characteristics of CNT composite-based sensor at operating temperatures of 38, 50, 100 and 150°C under an ethanol vapor concentration of 1,000 ppm.

Alcohol vapor concentration:

The response and recovery curves of CNT composite-based sensor under ethanol vapor concentration of 50, 100, 500 and 1,000 ppm at an operating temperature of 38°C are shown in Figure 3. At different ethanol vapor concentrations, the sensor resistance varies slightly.

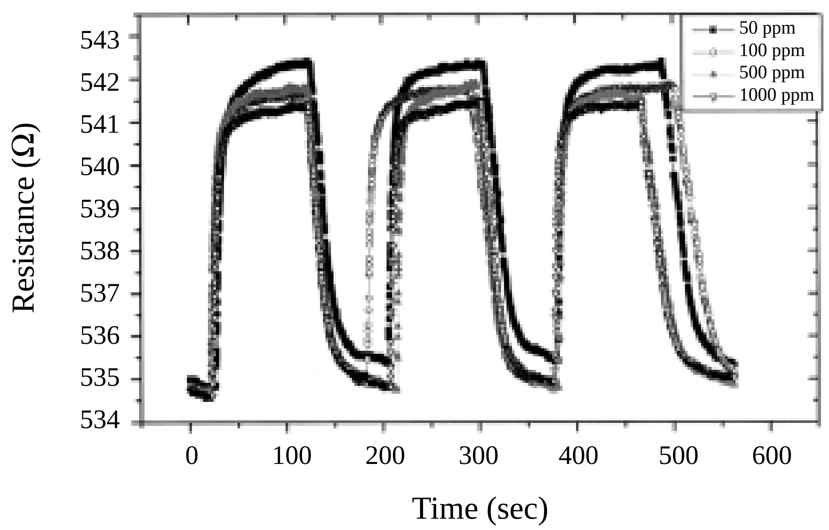

Figure 3. Response and recovery characteristics of CNT composite-based sensor under ethanol vapor concentration of 50, 100, 500 and 1,000 ppm at work temperature of 38°C.

Typical parameters used to determine the quality of a gas sensor are responsiveness, sensitivity and response time. The responsiveness S is defined $S = (R_a - R_o)/R_o$ where R_a is the electrical resistance of the sensor in air and Ro is its resistance in ethanol vapor. The sensitivity of the sensor is defined as R_a/R_o. The response time (τ_{90}) is defined as the time required for the sample resistance variation to reach 90% of equilibrium value following a step increase in the concentration of the testing gas. The resistance, responsiveness, sensitivity and response time of the CNT composite-based sensor obtained from the response and recovery curves are summarized in Table 1.

Table 1. Resistance, Responsiveness, Sensitivity and Response Time (τ_{90}) of CNT composite-based sensor at operating temperatures of 38, 50, 100 and 150°C and at operating temperature of 38°C under ethanol vapor concentration of 50, 100, 500 and 1,000 ppm.

	Work Temperature	**R_0 (Ω)**	**R_a (Ω)**	**Responsiveness $(R_a-R_0)/R_0$**	**Sensitivity (R_a/R_0)**	**Response time (τ_{90}) (sec)**
Ethanol vapor concentrations (1,000 ppm)	38°C	547.01	554.58	0.0138	1.0138	10
	50°C	536.35	539.61	0.0060	1.0060	28
	100°C	496.02	498.46	0.0049	1.0049	51
	150°C	476.74	478.73	0.0041	1.0042	46
	Ethanol vapor concentrations	**R_0 (Ω)**	**R_a (Ω)**	**Responsiveness $(R_a-R_0)/R_0$**	**Sensitivity (R_a/R_0)**	**Response time (τ_{90}) (sec)**
Work Temperature (38°C)	50 ppm	534.69	542.27	0.0142	1.014	17
	100 ppm	534.69	541.79	0.0133	1.013	17
	500 ppm	534.69	541.66	0.0130	1.013	13
	1,000 ppm	534.69	541.35	0.0125	1.012	10

At an ethanol vapor concentration of 1,000 ppm, the responsiveness and sensitivity of the sensor decreases while the response time increases with increasing temperature. This suggests that 38°C is the optimum operating temperature. Moreover, at 38°C the responsiveness, sensitivity and response time of the sensor decreases with increasing ethanol vapor concentration. The relation between ethanol concentration and the quality parameters is under intense research.

The gas sensor based on CNTs/PMMA composites for methanol and acetone vapor has been reported and the sensing mechanism has been explained on the basis of the volume expansion and polar interaction of these vapors on the carbon nanotube surface (Philip et al., 2003). Since our CNT composite-based sensor was tested with a similar organic vapor, we strongly believe that the sensing mechanism of our gas sensor could be explained by the similar explanation.

CONCLUSION

A thick film of carbon nanotube composite was prepared by mixing carbon nanotube powder with iso-butyl methyl ketone and painted onto alumina substrates. Then, the composite's gas-sensing properties were tested for ethanol vapor. It was found that the optimum operating temperature was 38°C. At 38°C, an increase in resistance of 2–5 ohm was observed with the responsiveness of about 0.01, sensitivity of about 1 and response time of about 10 sec. The sensing mechanism of the composite could be explained on the basis of volume expansion and polar interaction of vapors on the carbon nanotube surface.

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