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Static and dynamic strain sensing using a polymer - carbon nanotube film strain sensor

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1. Introduction

The search for new multipoint, multidirectional strain sensing devices has receieved a new impetus since the discovery of carbon nanotubes. The excellent electrical, mechanical, and electromechanical properties of carbon nanotubes make them ideal candidates as primary materials in the design of this new generation of sensing devices. Carbon nanotube based strain sensors proposed so far include those based on individual carbon nanotubes for integration in nano or micro elecromechanical systems (NEMS/MEMS) [1], or carbon nanotube films consisting of spatially connected carbon nanotubes [2], carbon nanotube - polymer composites [3,4] for macroscale strain sensing. Carbon nanotube films have good strain sensing response and offer the possibility of multidirectional and multipoint strain sensing, but have poor performance due to weak interaction between carbon nanotubes. In addition, the carbon nanotube film sensor is extremely fragile and difficult to handle and install. We report here the static and dynamic strain sensing characteristics as well as temperature effects of a sandwich carbon nanotube - polymer sensor fabricated by infiltrating carbon nanotube films with polymer.

2. Experiment

25mg of carbon nanotube were dispersed in 50ml of dimethylformamide (DMF) by bath sonication for 30minutes. A carbon nanotube film was obtained by filtering the DMF using a millipore filtration arrangement and a 0.2 microns Teflon membrane filters. After washing the solvent, the film was dried under vacuum at 80^{o}C for 12h. Once dried, the film with a thickness of 30-40μm was peeled off from the filter. An epoxy-TETA mixture 4:1 ratio was prepared and applied on a nano mould release coated aluminium plate before carefully placing the nanotube film on top, a drop of epoxy was then spread on the upper surface. The film was cured at room temperature for 24h under a smalll pressure applied using a hydraulic press. The cross section of the sandwich film sensor is shown the SEM image in Fig. 1. The image shows one section (upper part) with a high degree of CNT connectivity and a second section(lower part) with polymer only.

Electrical properties were characterised by measuring the resistance of the composite at temperatures between -20^{o}C and 50^{o}C and 63.1% relative humidity at a heating and cooling rate of 2.5^{o}C/min using a Votsch environment chamber. The strain sensing characteristics were obtained in simple tension while attached to a brass tensile specimen and in dynamic mode when attached to a stainless steel substrate connected to a shaker for generating sinusoidal displacement. Samples measuring 12mm by 6mm were used.

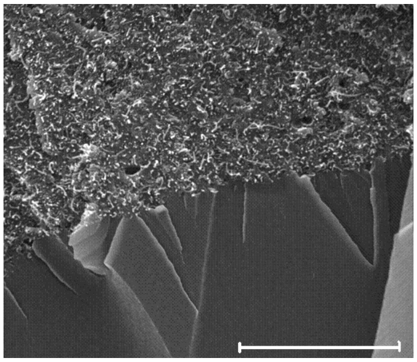

Figure 1. SEM image of sandwich film cross section. Scale bar represents 5μm.

3. Results and discussion

All samples cut out for strain sensing characteristics had nominal resistance between 100 and 170Ω. Short and long term stability at room temperature was

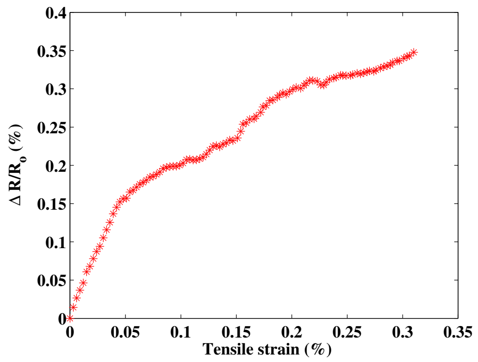

Figure 2. Tensile strain -% relative resistance change plot for sandwich sensor.

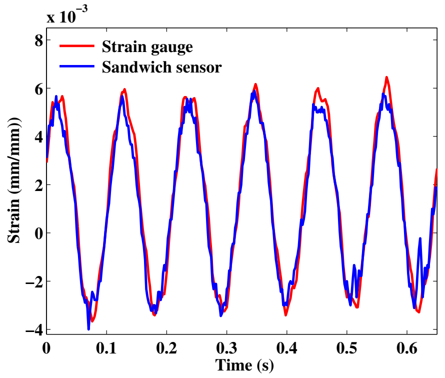

Figure 3. Dynamic strain sensing with a sandwich sensor and strain gauge at 10Hz.

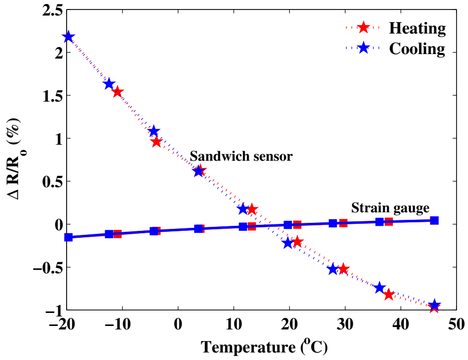

Figure 4. Temperature - % relative resistance change plot for sandwich sensor and strain gauge

within 0.055% of the nominal resistance, comparing very well with the stability of conventional metal foil strain gages. Figs. 2 and 3, reveal excellent static and dynamic sensing response of the sandwich sensor. The tensile strain - resistance response of the sandwich composite sensor can be divided into two regions as shown in Fig 2.The low strain region, between 0 - 600$\mu\varepsilon$ is linear with a strain gauge of 2.99 ± 0.51. The second region, between 600 - 3000$\mu\varepsilon$ shows a nearly linear response; the gage factor for this region is about 0.880 ± 0.138. The gage factor of commonly used metal foil strain gages is $\sim$ 2–3. Depending on factors such as fabrication process, carbon nanotube type, sensor type and matrix material gage factors between (3 –22.4) can be obtainedfor carbon nanotube-polymer composite sensors [3, 4]. The sandwich sensor tracks the dynamic strain very well, this is seen in Fig. 3 where the signal recorded by the strain gauge is matched by that recorded by the sandwich sensor. Temperature-% relative resistance change plot for sandwich sensor and conventional metal foil strain gauge is shown in Fig. 4 The sandwich sensor has a temperature coefficient of resistance of -0.048 ± 0.01/^{o}C compared to that of the metal foil strain gauge which was 0.002/^{o}C. Cycling the temperature several times at the same heating and cooling rate indicated that the sensor had no hysteresis, no degradation of sensitivity and no creep.

4. Conclusion

We have developed a new higher performance sandwich carbon nanotube - polymer sensor. This sensor has several distinct advantages over the randomly mixed epoxy-nanotube sensor. The sandwich sensor has lower and more stable resistance under no load conditions, less thermal induced change in strain (a lower thermal output), and no creep. Compared to carbon nanotube film sensors, the sandwich sensor is easier to fabricate and safer from a health and safety perspective while offering the same level of excellent performance.

References

[1] C. Neng-Kai, S. Chi-Chung, and C. Shuo-Hung, “Fabrication of single-walled carbon nanotube flexible strain sensors with high sensitivity,” *Applied Physics Letters*, vol. 92, no. 6, pp. 063 501–1, 2008.

[2] Z. Li, P. Dharap, S. Nagarajaiah, E. V. Barrera, and J. D. Kim, “Carbon nanotube film sensors,” *Advanced materials*, vol. 16, no. 7, pp. 640–643, 2004.

[3] N. Hu, Y. Karube, M. Arai, T. Watanabe, C. Yan, Y. Li, Y. Liu, and H. Fukunaga, “Investigation on sensitivity of a polymer/carbon nanotube composite strain sensor,” *Carbon*, vol. 48, no. 3, pp. 680–687, 2010.

[4] G. Yin, N. Hu, Y. Karube, Y. Liu, Y. Li, and H. Fukunaga, “A carbon nanotube/polymer strain sensor with linear and anti-symmetric piezoresistivity,” *Journal of Com-*

posite Materials, 2011.