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| 포스터 세션 |

스트레인 센서 응용을 위한 graphene/PDMS 나노 복합재료의 제조 및 평가

왕박* · 이봉기** · 이동원***

Fabrication and characterization of graphene/PDMS nano composite for strain sensors application

Bo Wang, Bong-Kee Lee and Dong-Weon Lee

1. Introduction

Graphene, the perfect two-dimensional (2D) crystalline carbon sheet with high Young's modulus and high strength [1], when used as conductive filler in polymers, graphene not only improve the mechanical properties but also present new functionality. Conductive graphene composites are sensitive to varieties of external stimulus, such as pressure, temperature and mechanical perturbation [2]. The sensitivity of graphene composites makes the application of the composites behave as smart materials in all kind of sensor applications. Graphene composites have the potential to realize a higher sensitivity to strain which means the gauge factor would be higher comparing to commercial coil strain gauges of cupronickel or nichrome. Our research demonstrates the fabrication and characterization of such composites for use in sensor applications and MEMS.

2. Theoretical basis

2.1 Theoretical equations

2.1.1 Gauge factor

In order to characterize the sensitivity of the graphene/PDMS composite, the gauge factor (GF) of the composite could be obtained with the equation

$$GF = \frac{\frac{\Delta R}{R}}{\frac{\Delta L}{L}} \qquad (1)$$

where R is the initial resistance of the sensor and △R is the relative resistance change under the deformation. L is the initial length of the sensor and △L is the relative elongation of the axial specimen.

2.1.2 Power law

The conductivity of the composite, σ_c, above the percolation threshold is treated with a power law [3]

$$\sigma_c = \sigma_f[\frac{\phi - \phi_c}{1 - \phi_c}]^t \qquad (2)$$

where σ_f is the conductivity of graphene, ϕ is the filler volume fraction and ϕ_c is the percolation threshold.

2.2 Research method

The gauge factor was obtained by measuring the resistance change and the specimen elongation to characterize the piezoresistivity of the composite. The conductivity was then measured and fitted by equation (2) to find whether the composite is in accordance with the theoretical basis.

3. Experimental

3.1 Fabrication of graphene/PDMS composites

The fabrication of graphene/PDMS composite relies on the common evaporation method. The PDMS (Sylgard 184) was purchased from Dow Corning Co.

*School of Mechanical Systems Engineering, Chonnam National University, Gwangju, Republic of Korea

**School of Mechanical Systems Engineering, Chonnarm National University, Gwangju, Republic of Korea

***School of Mechanical Systems Engineering, Chonnam National University, Gwangju, Republic of Korea. Electronic mail: mems@jnu.ac.k

and the graphene nanopowder (MO-1) from Graphene Supermarket. The appropriate amounts of THF were firstly added into the base polymer to decrease the viscosity of base polymer. The graphene was dispersed into THF with a ratio of 300mg graphene nanopowder per 20ml by using ultrasonicator (ultrasonic power 200W) for 2 hours. Afterwards the dispersed graphene/THF solution was mixed with the base polymer solution by using ultrasonicator for 4 hours to form PDMS base polymer/graphene composite in THF and decrease the macroscopic graphene clusters in the solution. The THF evaporation was processed in a fume hood by stirring the solution at 50℃. The curing agent was added to the dispersed graphene/PDMS base polymer emulsion. Then, the blended graphene/PDMS mixture emulsion was degassed for 30 min. Finally, the mixed composite was uniformly smeared onto 4mm-thick PDMS specimens. In order to fabricate a sensor, the smeared composite was cut into rectangular shape by blades, and cured at 60℃in oven for 10 hours. The final graphene/PDMS composite samples on PDMS specimens have thicknesses between 100 and 300μm. Two electrodes were connected to it with silver conducting epoxy to improve the contact as shown in Fig.1. The perfect bond between PDMS and the composite ensures the transfer of strain across the sensor simultaneous during the measurement.

3.2 Measurement of piezoresistive characteristics

The piezoresistance of the sensor was investigated with source meter (Keithley 2400). The elongation of the specimen was exerted and measured with universal test machine (SHIMADZU EZ-Test 500N), the loading speed was numerically controlled as shown in Fig. 2.

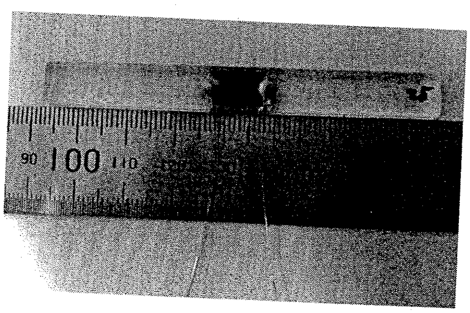

Fig.1 The specimen used as strain sensor during the tensile tests.

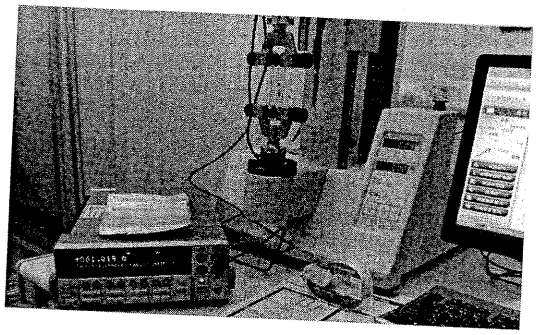

Fig. 2 The experiment set up with tensile machine and source meter

4. Results and discussion

The composite resistance change with tensile strain was illustrated in Fig. 3. The sensitivity of the composite is much higher than composites with higher filler concentration since it could be explained by the percolation theory [4]. The graphene/PDMS composite strain sensor shows a symmetrical response with gauge factors between 6.25 and 220, the gauge factor obtained within the range of 2000 micro strain [5].

The conductivity as a function of filler volume fraction was shown in Fig.4. The percolation threshold detected in our research is 8.15vol.%, which is higher than other polymer material composites due to the filler couldn' t dispersed uniformly in the PDMS solution which with high viscosity [6], but the conductivity shows the high consistency with the powder law.

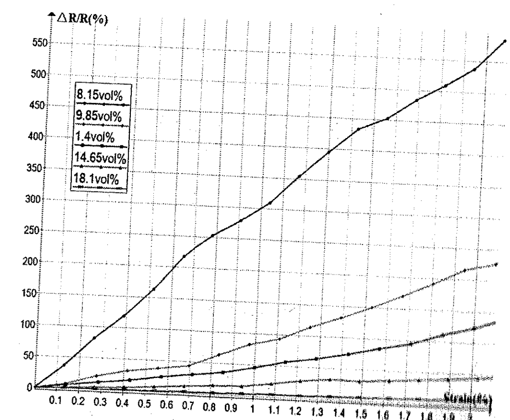

Fig. 3 Resistance change with tensile strain as the effect on composites with different filler volume fraction

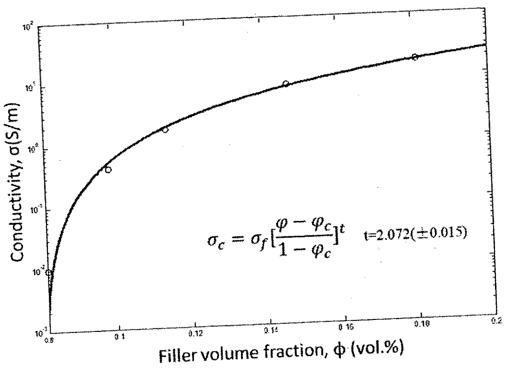

Fig. 4 Electrical conductivity of the graphene/PDMS composites as a function of filler volume fraction

5. Conclusion

This paper addresses the fabrication of graphene composites based on polydimethylsiloxane (PDMS). The composites using graphene nanopowder as conductive filler element have been investigated. The graphene/PDMS composite strain sensor shows a symmetrical and reversible piezoresistive response with gauge factors between 53 and 270, the gauge factor obtained within the range of 2000 micro strain. The graphene/PDMS composite strain sensor showed much higher strain sensitivity than both carbon nanotubes (CNTs) composite strain sensors and the strain gauge made of high-quality graphene films. The higher piezoresistivity of graphene composites compared to CNTs composites can be explained by the contact area of the resistance graphene. Conclusions about the suitability of these materials for use in MEMS are presented.

Acknowledgements

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