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Influences of compression cycles on piezocapacitive effect of carbon black filled silicone rubber composite

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ABSTRACT

The relation between the pressure and the capacitance of the carbon black filled silicone rubber composite with the carbon black content ranging from 5 vol.% to 9 vol.% (this content range can ensure the reinforcement effect and the flexibility of the composite for sensor development) under the multi compression cycles is researched. The capacitance of the composite increases with the increase of the pressure. There are deviations between the thicknesses/capacitivities of the composite under the same pressure in the different compression cycles, which results in the repeatability error of the piezocapacitivity of the composite. The experimental results show that the repeatability can be improved by increasing the number of the compression cycles. Therefore, the piezocapacitive effect of the composite has the potential to be used to measure the compressive pressure by applying the multi pre-compression cycles on the composite. The further analyses show that the hysteresis error, the nonlinear error and the sensitivity decrease with the increase of the number of the compression cycles.

1. Introduction

Conductive polymer composite, which is fabricated by dispersing the conductive fillers in the polymer matrix, plays important roles in the field of measurement. Many researchers have verified that the composite has the potential to be applied into the developments of the gas sensors [1,2], gap sensors [3,4], stress/strain sensors [5–9], temperature sensors [10,11], and humidity sensors [12,13], etc. As an important branch of the aforementioned investigations, the compressive pressure sensor based on the composite not only has solid research foundation but also exhibits broad application prospect. Therefore, the electrical properties of the composites during the compression, which are the keys to develop the compressive pressure sensor, have attracted more and more interests these years [14–19]. According to the previous researches [20–23], the conductive network composed of the conductive fillers in the composite can be changed under the compression. Therefore, as an important electrical property of the composite, the capacitance should also be changed with the variation in the conductive network. Accordingly, the conductive network in the composite can be considered as a piezocapacitive network [24–29]. Therefore, the composite has the potential to be used to develop the piezocapacitive sensor. However, there is a deviation between the structures for the conductive network of the composites under the same pressure in the different compression cycles [30–34]. Consequently, the piezocapacitivity of the composite is dependent of the compression cycle, which has great influences on the application of the composite in the sensor development. Therefore, it is needed to study the effects of the compression cycles on the key characteristics of the composite comprehensively. However, the previous researches on the piezocapacitivity of the composite are from the view of property investigation instead of sensor development. Up to now, there are no quantitative researches regarding the effects of the compression cycles on the key characteristics of the pieozcapacitive sensor based on the composite (e.g. repeatability). To solve the aforementioned limitations, in this paper, the piezocapacitivity of the composite has been studied form the angle of the sensor design. Compared with the previous researches on the piezocapacitive effect of the composite, the novelties of the work in this paper lie in that the effects of the compression cycle on the repeatability, hysteresis, sensitivity and linearity of the piezocapaictivity of the composite are researched quantitatively and the directions to develop the piezocapacitive sensor based on the composite are also given.

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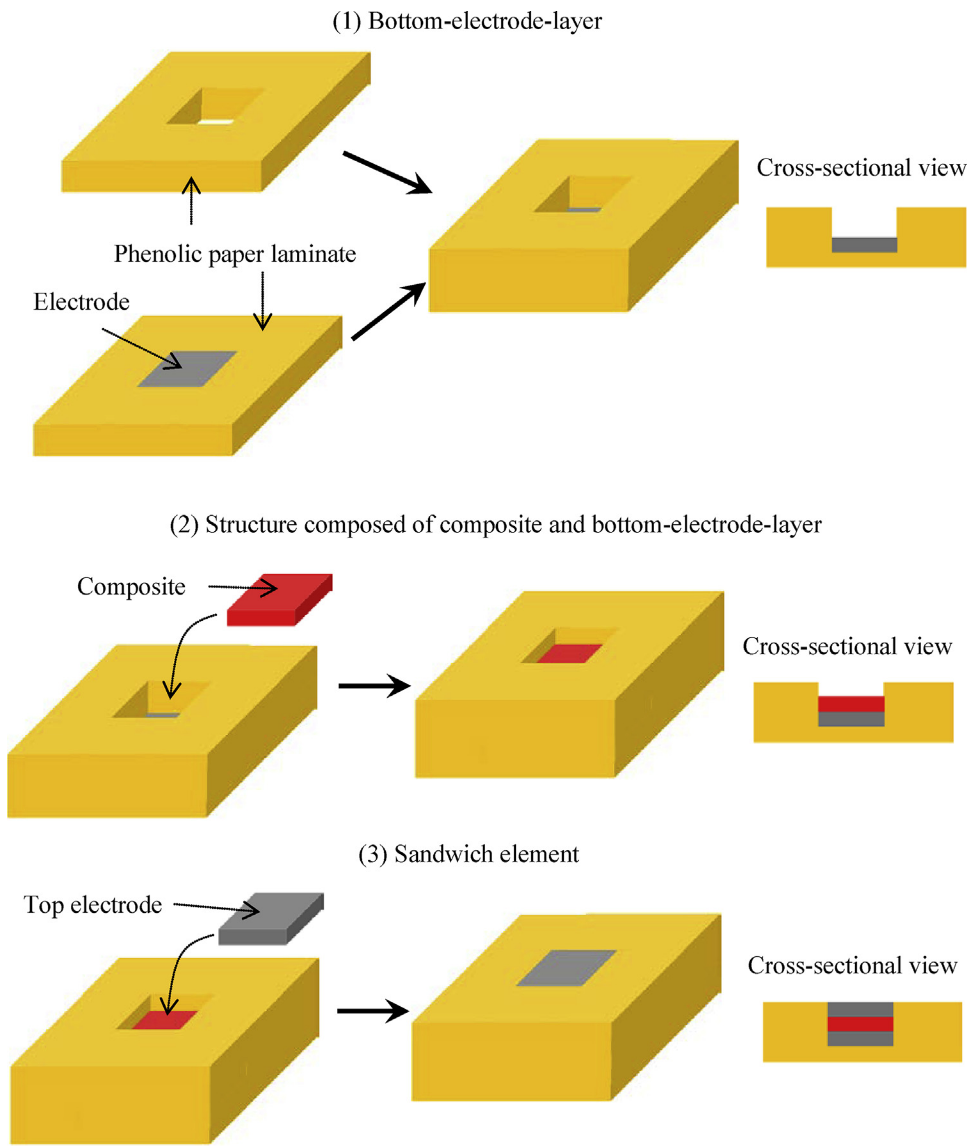

Fig. 1. Configuration and fabrication process of the sample.

2. Experiments

The sample is the sandwich element which is composed of the bottom-electrode-layer, the piezocapacitive-material-layer and the top-electrode-layer. Fig. 1(1) shows the configuration of the bottom-electrode-layer which has two parts. The first part is a hollow insulating platen made of the phenolic paper laminate which is rigid and insulating. The thickness of the platen is 2 mm. The hole, which is located on the center of the platen, is square (side length: 30 mm). The second part is a platen made of phenolic paper laminate covered with copper foil by using classical PCB (printed circuit board) technology. The copper foil (used as the electrode), which is located on the center of the phenolic paper laminate, is square (side length: 30 mm). Fig. 1(2) and (3) show the fabrication process of the sandwich element. The piezocapacitive-material-layer is made of conductive polymer composite. Carbon black is used as the conductive phase of the composite. Room temperature vulcanized liquid silicone rubber is used as the polymer matrix. The characteristics of the silicone rubber and the carbon black are shown in Table 1. According to the experiments on the mechanical properties, if the carbon black content is less than 5 vol.%, the reinforcement effect is not enough; if the carbon black content is more than 9 vol.%, the flexibility is deteriorated. Therefore, the useful range of the carbon black content is between 5 vol.% and 9 vol.%. The experiments in this paper are done within the aforementioned carbon black content range. Carbon blacks are dispersed into the silicone rubber by using the solution mixing method [35–37]. Tetraethoxysilane (Shenyang Chem. Plant, China) is used as the crosslinker. Hexane (Shenyang Chem. Plant, China) is used as a solvent to mix the carbon blacks into the silicone rubber. Mechanical stirring along with ultrasonic vibration is used for better filler dispersion. After 3 h of the vigorous mixing, the solvent is evaporated at 40 °C and the mixture composed of the carbon blacks and silicone rubber is left. As shown in Fig. 1(2), the mixture is dropped into the hole of the bottom-electrode-layer to form the structure

Table 1
Characteristics of carbon black and silicone rubber.

Carbon black	Resistivity	Specific surface area	PH
	<1 Ω cm	780 m^2/g	6.25
Silicone rubber	Dielectric constant	Hardness	Dielectric strength
	3	35 Shore	15 kV/mm