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Hydrostatic pressure sensor based on carbon sphere – polyvinyl alcohol composites

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ABSTRACT

We report on the preparation of hydrostatic pressure sensors, based on carbon sphere–polyvinyl alcohol composites deposited onto interdigitated electrodes, determining the pressure dependence of the conductance and capacitance of the devices. For these devices, we used carbon spheres with average diameter of 124 ± 13 nm at concentrations of 20%, 30% and 40%. The highest relative variation of conductance (0.69% kPa^{-1}) and capacitance (0.24% kPa^{-1}) was obtained using the composite with 30% carbon spheres.

1. Introduction

Pressure sensors are widely used in several different applications, like airflow measurement and in pressure control in confined vessels (for example tires, pipelines and microphones). Among the various existing pressure sensors [1–3], carbon black dispersed in a hosting polymer matrix has been demonstrated to constitute an interesting system due to the simple low-cost processes involved in their production, as well as their large and fast electrical response. Due to these advantages these systems have been applied to a number of pressure sensor systems, in most cases for uniaxial pressure measurement [4–7].

In conducting particles-host insulating polymer matrix composites, the pressure imposes changes on the average distance between the conducting particles mainly due to volume modification of the matrix, which changes the tunneling probability between conducting particles. By this mechanism, the conductance of the existing percolation paths is modified and new percolation paths may be created or suppressed, directly affecting the conductance of the medium. The capacitance of the system is also modified due to the variation of the separation distance of conducting particles by the insulating material.

In the past two decades a wide range of shaped carbon materials have been produced, including horns, onions, tubes, coils, etc. and many new methodologies to prepare the new and known shaped carbons have been extensively reported. This includes studies on spherical carbons (hollow, core/shell and fullerenes) [8] that are similar to the carbon blacks [9,10].

Herein we report on the use of carbon spheres (CSs) produced in a non-oxidizing environment, with a narrow size distribution, mixed with polyvinyl alcohol (PVA) as a hydrostatic pressure sensor. These CSs, with a narrow diameter range (124 ± 13 nm), are solid carbon balls made up of nanometric sized flakes, have a low surface area and are generally found accreted (Fig. 1). This means that clusters of the CSs are in contact with each other, similar to that found for carbon blacks. This accretion phenomenon should aid CSs in their ability to act in sensing devices.

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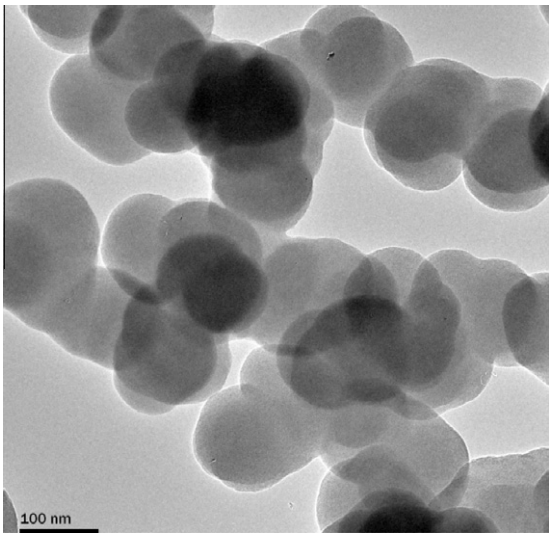

Fig. 1. Transmission electron micrograph of the carbon spheres.

2. Experimental

Polyvinyl alcohol was supplied by Sigma–Aldrich (average molecular weight 130,000) and used without further purification. The synthesis of the CSs was performed by passing a continuous flow of acetylene gas for 10 min at 900 °C, under an argon atmosphere through a quartz tube placed vertically inside a furnace. The acetylene and the argon gases were allowed to flow (100 mL/min each) from top to bottom through the quartz tube and the carbonaceous materials collected in a 500 mL round bottom flask, similar to that reported by Jin et al. [11]. The CSs were characterized by transmission electron microscopy (TEM) using a FEI Tecnai G2 Spirit electron microscope at 120 kV.

The devices were prepared as follows: PVA was added to 1,2-dichlorobenzene and the solution was heated to 80 °C and stirred for 30 min. This gave a homogeneous solution of PVA in the solvent (115 mg/mL). CSs were added to another sample of 1,2-dichlorobenzene, stirred for 30 min and ultrasonicated for 30 min at room temperature, using a 45 W ultrasonic bath, to obtain a uniform dispersion of CSs (2.2 mg/mL). Both solutions were then mixed at room temperature in a proportion chosen to give final solution compositions containing 20%, 30% and 40% CSs (w/w) concentration in the composite.

The pressure sensors used in this work were prepared by depositing the CS–PVA dispersion onto a $8 \times 9\ mm^2$ phenolite printed circuit board with nine pairs of 7.5 mm long tin-coated cooper interdigitated electrodes having a gap of 0.3 mm between them, in a rectangular geometry, as reported elsewhere [12,13]. A μL-pipette was used to deposit a CS–PVA dispersion by sequentially dropping 20, 30 and 35 μL (time interval of 60 min) onto the phenolite substrates.

The devices were then electrically characterized using a programmable Agilent 4284A LCR meter. An AC-signal amplitude of 500 mV was used as the operating voltage under environmental conditions. The pressure dependence measurements were made by placing the sensor in a cylindrical tube with a diameter of 44.5 mm in which the pressure was controlled manually with the aid of a piston (Fig. 2) following the relationship $h_i p_i = h_f p_f$, *i.e.*, the pressure in the cylindrical tube was varied by displacing the piston (h is the height, p is the pressure, i denotes initial and f denotes final) and neglecting the volume of the sensor.

3. Results and discussion

The transmission electron microscope (TEM) image of the CSs produced is shown in Fig. 1. From these TEM images it is evident that the solid CSs are accreted and have a narrow size distribution (diameter: 124 ± 13 nm). The synthesis of the spheres right from the beginning leads to accretion. Clustering of the spheres occurs either due to chemical interaction (accretion) or due to van der Waals interactions. The carbon chains involve from 2 to ~10

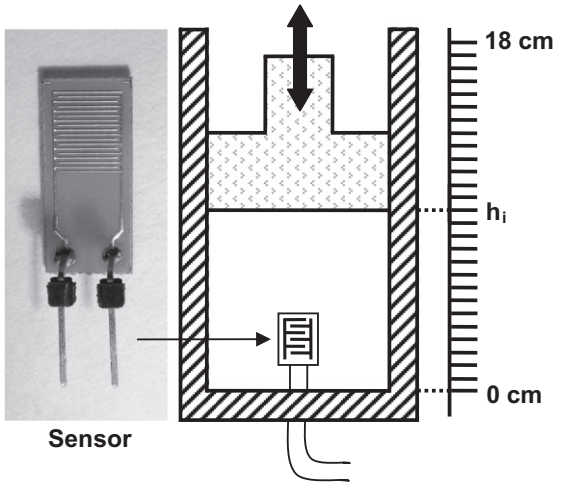

Fig. 2. Scheme of the experimental setup used for the pressure variation.

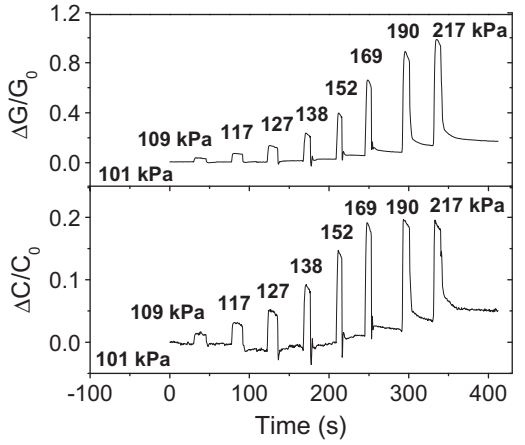

Fig. 3. Illustration of the electrical response of the device to pressure pulses of different magnitude.