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Production and Applications of Carbon Nanotube Buckypapers

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ABSTRACT: The present work aimed to prepare and characterize carbon nanotube (CNT) buckypapers (BPs) and to provide a perspective on possible applications in the optical device industry and power generation through triboelectric nanogenerators. The CNTs were dispersed in aqueous solution with the aid of a dispersing agent and then vacuum filtered. The prepared buckypaper has low average optical reflectance and shows an improvement in electrical conductivity and power generation when silver nanowires were added. This material includes new horizons and future applications for carbon nanotube buckypapers, including aerospace applications.

KEYWORDS: Carbon nanotubes; Buckypaper; Triboelectric nanogenerator.

INTRODUCTION

The constant search for materials with new properties led Iijima to discover carbon nanotubes (CNTs) in 1991 (Iijima 1991). The complete elucidation of the physical structure of carbon nanotubes is largely credited to Iijima's work, which characterized them by detailed scanning electron microscopy (SEM) images. Shortly thereafter, theoretical work by several groups determined that CNTs have unique and diverse intrinsic properties, including electrical, thermal, and optical properties (Bethune *et al*. 1993; Dalton *et al*. 2003; Azoubel *et al*. 2015). Since then, researches and a better understanding of this material have led to efforts in the search for potential applications of carbon nanotubes (Campos *et al*. 2017; Han *et al*. 2019; Xu *et al*. 2018).

This constant study has attracted new perspectives and future applications of CNT materials (Chen *et al*. 2016; Chinnappan *et al*. 2016). Among them, the buckypaper (BP) can be highlighted. This material consists of a dispersed matrix of carbon nanotubes arranged as a flat paper and held together by Van der Waals interaction. Due to its low reflectance, buckypaper is a potential material for applications in optical devices such as telescopes and materials requiring low optical noise (Azoubel *et al*. 2015). In addition, BPs or BP-copper composites could replace copper or aluminum foils on aircraft wings and fuselage to provide lightning protection, thus obtaining a great decrease in the aircraft weight, which would lead to a better performance and reduced fuel consumption (Liu *et al*. 2019; Khopade and Chopade 2018).

Power generation for self-sustaining systems is also an area of great interest as conventional batteries have many limitations such as high weight, low efficiency, difficulty of large-scale production, alternating current output, low power generation and short average life. Seeking a way around these limitations, triboelectric nanogenerators (TENGs) were developed based on the

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triboelectric effect to convert mechanical energy into electrical energy in a clean manner (Zhang and Wang 2018; Wang 2017). Its operation is based on the contact electrification of two materials, usually polymers, connected to a circuit through electrodes. Buckypaper is also an excellent material for use in electromagnetic interference shielding because it is a good conductor and is nanostructured. Because of the latter, incident electromagnetic radiation encounters many obstacles and is reflected multiple times and absorbed, even considering the small thickness of the BP (Poothanari *et al.* 2019).

The aim of the present study is to present the production of low-cost carbon nanotube buckypapers and applications for energy generating materials as well as optical devices.

MATERIALS AND METHODS

The multi-walled carbon nanotubes used were supplied by CTNano/UFMG, with purity greater than 95%, tube lengths ranging from 5 to 30 m and diameters ranging from 10 to 50 nm. For the production of buckypapers, the CNTs were dispersed with the aid of a sonicator in an aqueous solution containing 0.5 wt. % Triton X 100 surfactant to prevent their agglomeration. Vacuum filtration technique was also employed to percolate the suspension containing CNTs through a Teflon membrane to obtain a homogeneous end-product as shown in Fig. 1a.

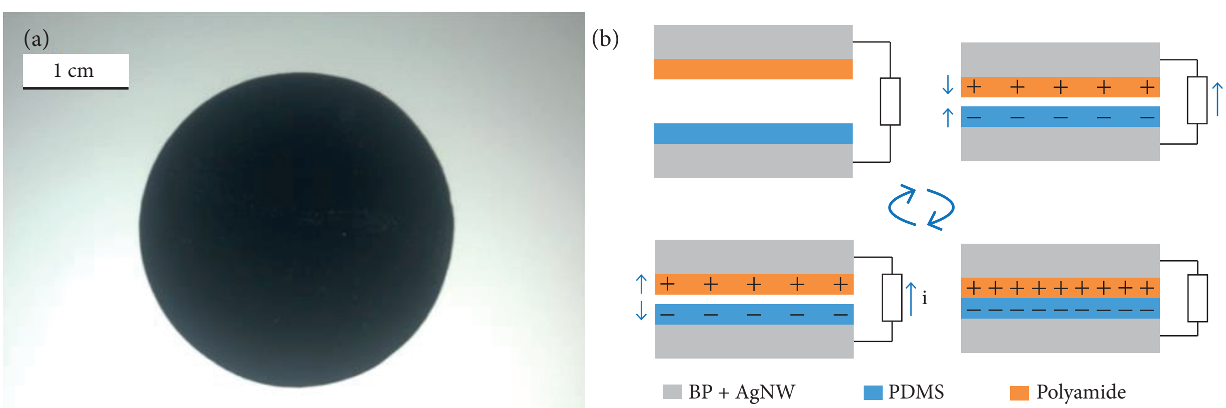

Figure 1. (a) Buckypaper after membrane separation; (b) representation of the working principle of the TENG.

The polydimethylsiloxane (PDMS) used in this work was Sylgard184 (Dow Corning), which is composed of a prepolymer and curing agent, which were mixed at a ratio of 10:1. Polyamide 11 (Nylon 11) was used as the other polymeric layer. Thin layers of polyamide 11 were prepared by hot press (250 °C) followed by a cold press for demolding. The PDMS and polyamide polymeric layers are shown is the schematic representation in Fig. 1 (right) in blue and orange, respectively.

Silver nanowires (AgNWs) were synthesized in the laboratory by a polyol method, which consists in the reduction of silver nitrate by ethylene glycol at high temperatures. In the synthesis, 94 mM $AgNO_3$, 3 mM HCl and 147 mM PVP-55 were used, and the solution was homogenized under heating at 140 °C for 16 h.

Diffuse reflectance measurements (Evolution 300, Thermo Scientific) were performed in the visible light region with a scanning speed of 30 nm/min. The reflectance of the BP was also calculated as a function of solar spectrum radiation.

RESULTS

Through visual inspection it is possible to verify the importance of surfactant use during the dispersion stage of carbon nanotubes. It is possible to visually identify (Fig. 2) that nanotubes remained dispersed even one day after the dispersion step with sonicator. The good dispersion is a consequence of the use of the dispersing agent Triton X-100, which has an unzippering mechanism (Strano *et al.* 2003). Thus, during the ultrasonic dispersion process, the agglomerates undergo separation due to the action of the sonicator compression and decompression waves. Thus, a process of gradual exfoliation of the individual nanotubes occurs where the surfactant molecules will act.

(a) (b)

Figure 2. Photographic record of nanotube dispersion without (a) and with (b) the use surfactant.

Figure 3a shows the matrix of CNTs prepared with the aid of the dispersing agent and in aqueous solution. It can be seen that carbon nanotubes are well dispersed and scattered randomly. Figure 3b presents the BP decorated with silver nanowires. The micrograph shows that the synthesis of AgNWs was successful and their integration with the MWCNT occurred homogeneously.

(a) (b)

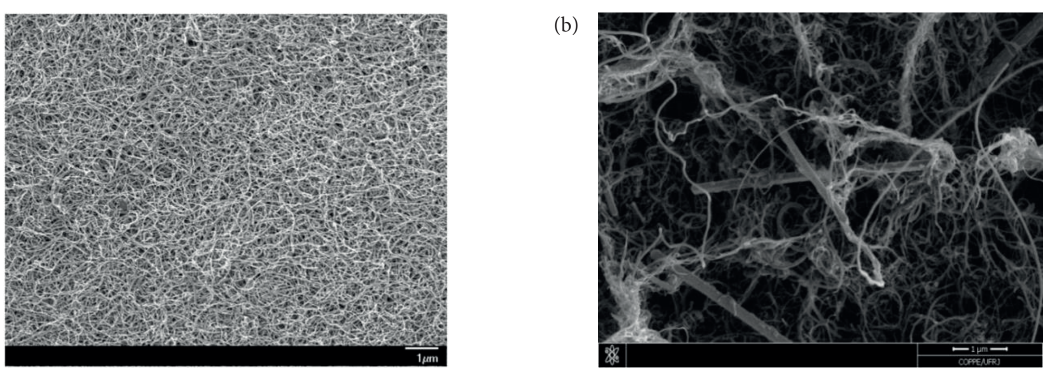

Figure 3. (a) Scanning electron microscopy of BP prepared with Triton-X100, (b) BP prepared with silver nanowires.

Reflectance measurements were performed and the results show that the BP has low reflectance, covering its applications for high-sensitivity aerospace optical devices. The average reflectance found as a function of solar irradiance was 0.77% in the visible spectrum between 400 and 700 nm.

In TENG measurements, the addition of AgNWs increased both charge and output voltage compared to pure the BP. Measurements were made on electrodes without polymeric coating and TENGs (electrodes with polymeric coating). Samples BP 1 and BP 2 are pure BP with different carbon nanotube concentrations, with BP 2 containing a higher MWCNT concentration than BP 1. Sample BP + Ag is the identical to BP 2 but containing 40% of its weight in AgNWs. The BP + Ag sample generated 50% more charge and 12% higher voltage than BP 2 (Fig. 4). Because PDMS is in contact with the entire surface of BP + Ag, the transmission of charge by AgNW in the BP was facilitated. The most significant results were the maximum charge density (1.55 nC/cm^2) and the maximum voltage density (2.33 V/cm^2), both obtained from a TENG with the BP + Ag electrode.

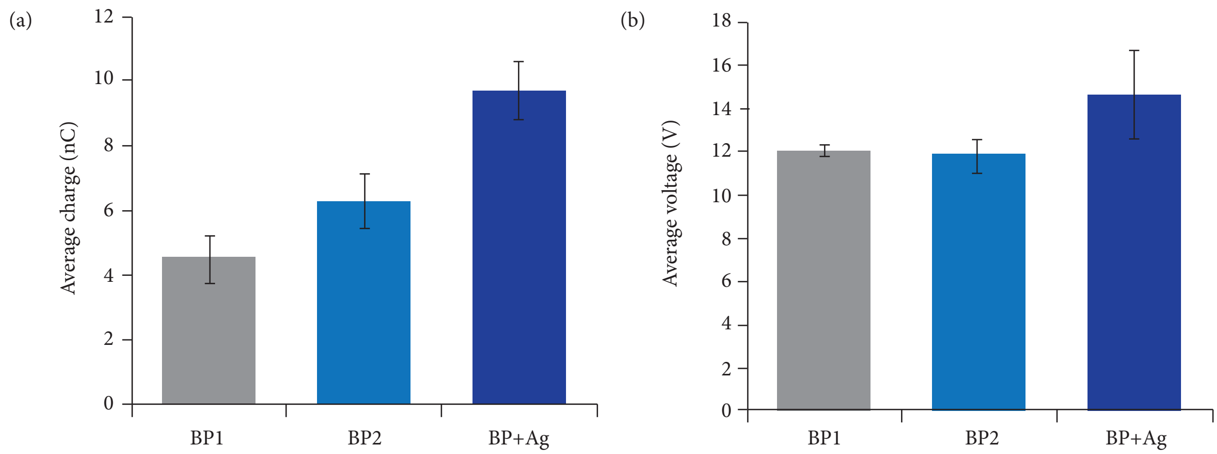

Figure 4. Average charge (a) and average voltage (b) obtained with TENGs with different electrodes.

CONCLUSIONS

Carbon nanotube sheets, known as buckypapers, were prepared and characterized. A good dispersion of the CNTs was performed with of Triton X-100 surfactant and the aid of a sonicator. The material showed optical reflectance of 0.77%, which indicates that it can be a promising material for aerospace optical device applications. The addition of AgNWs improved the charge density and output voltage of the triboelectric nanogenerators. Increasing the amount of AgNWs can further improve these properties and make the nanogenerator a viable way to power portable and self-contained systems and provide clean electrical power to places with little or no electricity available.

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AUTHORS' CONTRIBUTION

Conceptualization, Campos RBV; Rocha TFD and Camargo Junior SS; Methodology, Campos RBV and Rocha TFD; Research, Campos RBV, Rocha TFD and Camargo Junior SAS; Writing - First version, Campos RBV and Rocha TFD; Writing - Review & Editing, Rocha TFD, Camargo Junior SAS and Campos RBV; Acquisition of Funding, Campos RBV and Rocha TFD; Resources, Campos RBV; Rocha TFD and Camargo Junior SAS; Supervision, Camargo Junior SAS.

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