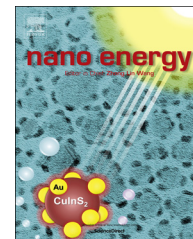




Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/nanoenergy



RAPID COMMUNICATION

A facile method to increase the charge storage capability of polymer nanocomposites



Aboutaleb Ameli^a, Sai Wang^b, Yasamin Kazemi^b, Chul B. Park^{b,*},
Petra Pötschke^c

^aAdvanced Composites Laboratory, School of Mechanical and Materials Engineering, Washington State University Tri-Cities, 2710 Crimson Way, Richland, WA 99354, USA

^bMicrocellular Plastics Manufacturing Laboratory, Department of Mechanical and Industrial Engineering, University of Toronto, 5 King's College Road, Toronto, Canada M5S 3G8

^cLeibniz Institute of Polymer Research Dresden (IPF), Hohe Straße 6, D-01069 Dresden, Germany

Received 21 November 2014; received in revised form 10 April 2015; accepted 10 April 2015

Available online 22 April 2015

KEYWORDS

Dielectric permittivity;
Dielectric loss;
Charge storage;
Carbon nanotube;
Microcellular structure

Abstract

A class of microcellular polymer nanocomposites of multi-walled carbon nanotubes (MWCNT) is reported that exhibits a stable and significantly high dielectric permittivity coupled with a stable and low dielectric loss in a wide range of frequency. Polypropylene (PP)-MWCNT nanocomposites with a cellular structure were prepared by melt mixing followed by physical foaming in an injection molding process. The generation of a cellular structure inside the nanocomposites provides a unique planar-like arrangement of the MWCNTs around the cells. This enhances the dielectric permittivity of nanocomposites up to an order of magnitude. Therefore, microcellular PP-1.25 vol% MWCNT presents a dielectric permittivity of $\epsilon' = 57.2$ and a dielectric loss of $\tan \delta = 0.05$ at 0.1 MHz, highly superior to the best values of the solid nanocomposites prepared by regular compression molding ($\epsilon' = 14.1$ and $\tan \delta = 0.39$) and by injection molding ($\epsilon' = 17.8$ and $\tan \delta = 0.04$). Also, microcellular PP-1.66 vol% MWCNT exhibits $\epsilon' = 95.6$ and $\tan \delta = 0.14$, which surpasses the dielectric performances reported in the literature. Hence, these nanocomposites with a cellular structure provide a novel and general approach to develop microscopically tailored structures for dielectric applications using facile methods. Such dielectrics can be used for energy storage in modern electronics and electrical power systems.

© 2015 Elsevier Ltd. All rights reserved.

Introduction

Dielectric materials with high dielectric permittivity (ϵ') and low dielectric loss ($\tan \delta$) are of great importance for charge storage applications in numerous industries such as modern

*Corresponding author. Tel.: +1 416 978 3053;
fax: +1 416 978 0947.

E-mail address: park@mie.utoronto.ca (C.B. Park).

Table 1 Dielectric properties of various polymer nanocomposites.

Work	Polymer matrix	Nano-additive	Frequency (Hz)	Dielectric permittivity	Dielectric loss	Fabrication method
Yang [2]	Polypyrrole	MWCNT: 8 wt%	10^2	44	0.07	Inverse micro-emulsion polymerization
Liu [3]	Polysulfone	MWCNT: 25 vol%	10^6	55	0.05	Surface modification of MWCNTs followed by solution/sonication mixing and electrospinning
Kim [9]	Cyanoethyl pullulan polymer	CNT+Reduced graphene oxide: 0.06 wt%	10^2	32	0.05	CNT/reduced graphene oxide platelets fabricated by thermal CVD followed by solution mixing
Liu [10]	Polyimide	Graphene+BaTiO ₃ : 1 vol%+16 vol%	10^2	31	0.03	Multiple step solution mixing
Hu [11]	Polyvinylidene fluoride	BaTiO ₃ nanoparticles +BaTiO ₃ nanofibers: 30 vol%+3 vol%	10^2	27	0.06	Solution mixing followed by layer-by-layer casting of multilayer films
Tian [12]	Polydimethylsiloxane	Thermally expanded graphene nanoplates: 2.0 wt%	10^3	89	1.5	Thermal exfoliation of graphene followed by solution mixing and vulcanization
Ameli [13]	Polypropylene	MWCNT: 0.34 vol%	10^2	30	0.06	Melt mixing and batch foaming

electronics, electrical power systems, hybrid electric vehicles, medical defibrillation, and smart grids [1-4]. Currently, neat polymers are the industrial choice of dielectric materials for charge storage applications, due mainly to their high breakdown strength. But the dielectric permittivity of neat polymers is very low (e.g., $\epsilon' < 3$ for polypropylene), and this limits their applications [5,6].

Polymer composites have shown great promise in overcoming the dielectric limitation of neat polymers. One practice is to add ceramic fillers, which can increase ϵ' of polymer by about ten-fold at loadings close to 50 vol% [7,8]. However, ceramic fillers at such loadings are detrimental to the composite's mechanical performance and sometimes to their electromechanical reliability [1,6]. An alternative approach that has been recently proposed is to use percolative polymer nanocomposites filled with highly conductive additives such as carbon nanotube and graphene [1,3,6]. In percolative nanocomposites, ϵ' significantly increases near the percolation threshold. However, this increase is usually coupled with a huge increase in $\tan \delta$ due to the sharp insulation-conduction transition. Consequently, their dielectrics applications are restricted.

Various strategies such as coating and surface modification of multi-walled carbon nanotubes (MWCNT) [1,6], MWCNT alignment by electrospinning [6], the use of hybrid additives [9,10], and the modulation of topological structure [11] have been proposed to develop polymer composites that are effective dielectrics. Table 1 summarizes some of the recent advances on the dielectric polymer nanocomposites. Nevertheless, all these fabrication methods are batch-type processes, which make them time-consuming, expensive, and not easily scalable. Moreover, in most cases, the required nano-additive loading remains rather high.

Polymer foaming has shown promises in promoting the conductive nanocomposites for various applications [13-20]. The introduction of foaming not only reduces the matrix weight significantly, but it can also be used to effectively

alter the functional properties of polymer nanocomposites. In foaming with supercritical gas, the dissolved gas improves the dispersion [21], the distribution [18,19,22], and the breakage [19,20] of the conductive additive during processing. More importantly, the growth of cells during foaming alters the orientation and alignment of the fillers around the cells via the biaxial stretching of the polymer matrix [13,18,19,21,23]. The electrical conductivity [13,19,20,24-26] and the electromagnetic interference shielding effectiveness [14,17,19,20] of conductive composite foams have been examined. Very little attention, however, has been paid to the potential impact of foaming on the dielectric properties. In a recent study, we demonstrated that the dielectric properties of polypropylene (PP)-MWCNT nanocomposites were enhanced by a foaming action [13]. We reported $\epsilon' = 30$ and $\tan \delta = 0.07$ for PP-0.34 vol % MWCNT foams (Table 1) that were prepared using a batch-type foaming process [13].

Contrary to the batch-type methods, injection molding is a common industrial technology used to produce conductive polymer composites. Recently, it was reported that the MWCNT alignment obtained through injection molding could contribute to the enhancement of the dielectric properties of polystyrene/MWCNT composites [27]. Moreover, Ameli et al. have also shown that foam injection molding alters the microstructure, resulting in a lowered electrical percolation threshold and in enhanced electrical conductivity in polymer composites [18-20]. Therefore, physical foaming combined with injection molding may provide a facile method to generate interesting microstructures favorable to enhanced dielectric properties. However, to the best of our knowledge, no effort has yet been reported on the dielectric performance of foam injection-molded nanocomposites.

Here, we report a facile preparation method of microcellular PP-MWCNT nanocomposites using injection molding for dielectric applications and characterize their electrical conductivity, real and imaginary permittivity, dielectric loss,

Download English Version:

<https://daneshyari.com/en/article/1557368>

Download Persian Version:

<https://daneshyari.com/article/1557368>

[Daneshyari.com](https://daneshyari.com)