G Model
APSUSC-29511; No. of Pages 4
ARTICLE IN PRESS
Applied Surface Science xxx (2015) xxx–xxx
Contents lists available at ScienceDirect
Applied Surface Science
journal homepage: www.elsevier.com/locate/apsusc

Nanostructured composite layers for electromagnetic shielding in the GHz frequency range

M. Suchea[a,b], I.V. Tudose[b,a], G. Tzagkarakis[a,d], G. Kenanakis[a,c], M. Katharakis[a], E. Drakakis[d], E. Koudoumas[a,d,*]

[a] Center of Materials Technology and Photonics, School of Engineering, Technological Educational Institute of Crete, Heraklion, Greece
[b] Chemistry and Physics, "Al.I. Cuza" University of Iasi, Iasi, Romania
[c] Institute of Electronic Structure & Laser (IESL), Foundation for Research and Technology (FORTH) Hellas, Heraklion, Greece
[d] Electrical Engineering Department, School of Engineering, Technological Educational Institute of Crete, Heraklion, Greece

ARTICLE INFO

Article history:
Received 14 November 2014
Received in revised form 2 January 2015
Accepted 10 January 2015
Available online xxx

Keywords:
Paint-like nanocomposites
Graphene nanoplatelets
Electromagnetic shielding

ABSTRACT

We report on preliminary results regarding the applicability of nanostructured composite layers for electromagnetic shielding in the frequency range of 4–20 GHz. Various combinations of materials were employed including poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS), polyaniline, graphene nanoplatelets, carbon nanotubes, Cu nanoparticles and Poly(vinyl alcohol). As shown, paint-like nanocomposite layers consisting of graphene nanoplatelets, polyaniline PEDOT:PSS and Poly(vinyl alcohol) can offer quite effective electromagnetic shielding, similar or even better than that of commercial products, the response strongly depending on their thickness and resistivity.

1. Introduction

In recent years, various high frequency electronic devices have been developed and used in mobile communication, radio navigation, television and various other signal processing and transmission systems. All these systems result in an increasing of the electromagnetic radiation background, which, being different from the natural one, can introduce a complex influence on biological systems as well as in the operation of electronic devices. This is known as electromagnetic interference, an effect that can cause malfunction of sensitive medical devices and robotic systems or even become harmful to life [1].

In order to address the electromagnetic interference problems, it is necessary to develop materials that can absorb or reflect the electromagnetic radiation of a particular range of frequencies, these materials offering electromagnetic shielding. The shielding materials normally must possess good electrical conductivity and dielectric constant, properties found in metals [2]. As a result, metals such as aluminium, copper and steel have been employed for electromagnetic shielding, in forms like sheet metal, metal screen and metal foam. The construction of a shield is very important for its effectiveness since any holes in the shield or mesh must be significantly smaller than the wavelength of the radiation that should be kept out, or the shield will not effectively block the incoming radiation. In that respect, there are several limitations in the applicability of metals in shielding applications since they are heavy, not easily handled/applied and they suffer from corrosion. As a result, the scientific community is trying hard the last few years to develop new shielding materials, trials that has been significantly supported by the advances in materials science and nanotechnology.

Conducting nanostructured layers and composites have gained popularity for electromagnetic shielding applications, especially in the GHz frequency range, because they present several advantages over conventional metals, such as light weight, corrosion resistance, flexibility, etc. As an example, polymer composites containing carbon-based fillers (e.g., graphite, carbon black, carbon fibers, and carbon nanofibers [3–7]) have been investigated for use as shielding materials in the high frequency range, owing to their unique combination of electrical conduction, polymeric flexibility, and light weight. More recently, graphene and polyaniline have also been tested as shielding materials [8–12], however, the so far results did not allow yet their use in commercial applications and further research is required regarding layer composition, growth methods and understanding of the underlying mechanisms.

In this work we present experimental results related to the electromagnetic shielding properties of paint-like nanocomposite layers based on graphene nanoplatelets. As found out, these nanocomposite s exhibit quite effective shielding in the GHz spectral

* Corresponding author at: Electrical Engineering Department, School of Engineering, Technological Educational Institute of Crete, Heraklion, Greece.
Tel.: +30 2810370887; fax: +30 2810379845.
E-mail address: koudoumas@staff.teicrete.gr (E. Koudoumas).

http://dx.doi.org/10.1016/j.apsusc.2015.01.074
0169-4332/

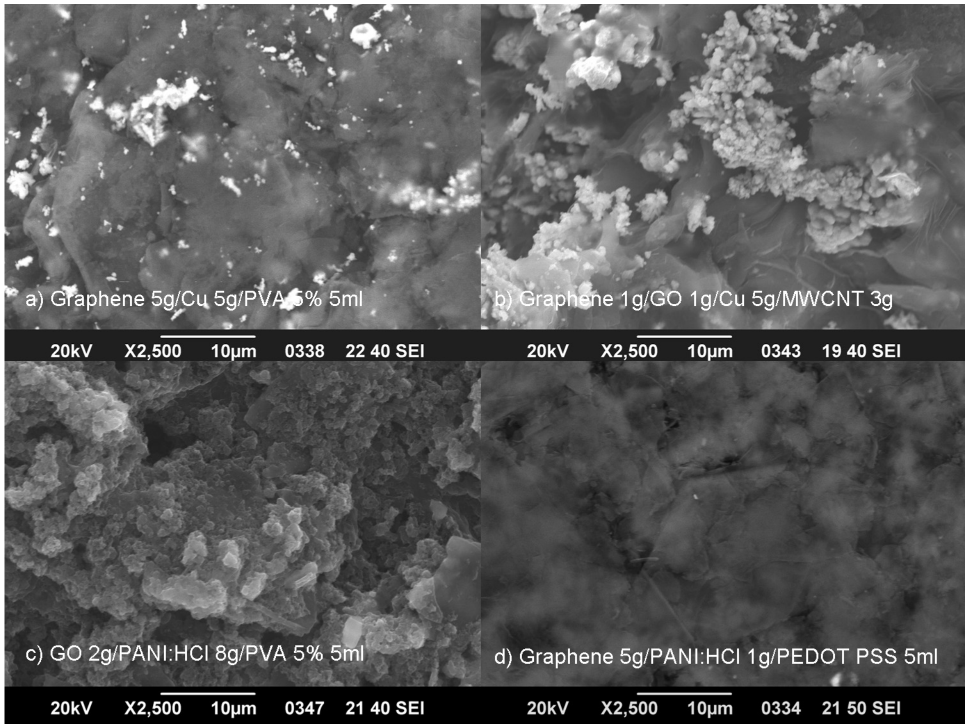

Fig. 1. SEM images of various nanocomposite layer compositions.

range, comparable to that of commercial products, while their effectiveness is depending on the resistivity and the thickness of the layers.

2. Experimental

The electromagnetic shielding layers under investigation were applied on 30 cm × 30 cm foam board by brushing paint-like dispersions in deionized water, prepared by ultrasonication. The main nanomaterial employed was graphene nanoplatelets, provided by EMFUTUR Technologies Ltd. Spain, 5 μm wide, with an average 5 nm thickness, a bulk density of 0.03–0.1 g/cm^3, a carbon content of >99.5 wt%, an oxygen content of <1% and a residual acid content of <0.5 wt%. Other nanomaterials used in the initial trial were:

(a) Cu nanoparticles, obtained by the reduction of copper salts with hydrazine in the presence of polyvinylpyrrolidone. The Cu nanoparticles were solution mixed with the other materials used to prepare the shielding layer.
(b) Commercial conductive multi wall carbon nanotubes (MWCNT) (carbon purity min 95%, number of walls 3–15, outer diameter 5–20 nm, inner diameter 2–6 nm, length 1–10 μm, apparent density 0.15–0.35 g/cm^3, loose agglomerate size 0.1–3 m) provided by EMFUTUR Technologies Ltd. Spain.
(c) Homemade graphene oxide sheets (GO), 1–1.2 μm in size, 5 nm thick, with an average number of 16 layers, prepared according to a modified Hummers' method [14]. The obtained material was quite clean, with small traces only of potassium besides oxygen and sulfur.

In addition poly(vinyl alcohol) (PVA) was used in some cases as a binder (Mowiol® 18-88 from Sigma Aldrich), while, PEDOT/PSS solution (Clevios^{TM} PH 1000) was employed as both a binder and a conductive medium. Finally, for the improvement of the electromagnetic shielding performance, Polyaniline:HCl (PANI:HCl) was added in some of the dispersions, prepared by polymerizing aniline hydrochloride in 1 M HCl using ammonium peroxydisulfate as a initiator in an ice bath according to IUPAC standard procedure [13]. All compositions were slowly stirred for 2 h in order to remove the trapped air bubbles and to ensure reasonable macroscopic homogeneity. The as prepared mixtures were spread on the foam board substrates using a brush follow by natural drying. The deposition procedure was repeated for several times until a material of the required thickness was prepared. Finally, layers of similar thickness made from commercial electromagnetic shielding were prepared and used as standards in order to evaluate both the performance of the experimental setup for the transmission measurements and the effectiveness of nanocomposite layers under investigation. Samples were visually inspected and characterized by scanning electron microscopy. SEM characterization was performed using a JEOL JSM 6362LV electron microscope. Regarding the transmission measurements, these were performed in air, using a Hewlett-Packard 8722 ES vector network analyzer and four sets of microwave standard-gain horn antennas covering the range 3–24 GHz. Prior to every measurement, an absorbing chamber was created using typical microwave absorbers (ECCOSORB AN-77, Emerson & Cuming Microwave Products, Inc., Randolph, MA) over all surfaces except the top, and each sample was placed in the middle of each set of horn antennas.

3. Results and discussion

Initially, several layers of various nanocomposites based on different combinations of materials were prepared and tested, so that the one exhibiting optimum electromagnetic shielding can be chosen and studied further. Four types of material combinations were examined:

(a) graphene nanoplatelets with Cu nanoparticles and PVA,
(b) graphene nanoplatelets with MWCNT, GO and Cu nanoparticles,
(c) GO with PANI:HCl and PVA,
(d) graphene nanoplatelets with PEDOT:PSS and PANI:HCl.

Please cite this article in press as: M. Suchea, et al., Nanostructured composite layers for electromagnetic shielding in the GHz frequency range, Appl. Surf. Sci. (2015), http://dx.doi.org/10.1016/j.apsusc.2015.01.074