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RESEARCH PAPER

Optimal Design of a Lightweight and Thin Radar Absorbing Nanocomposite

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ABSTRACT

Recently, attention to polymeric nanocomposites has gained a great extent as they present new opportunities to provide superior properties in microwave absorbing materials. In this study polystyrene (PS) nanocomposites containing various nano-fillers were successfully synthesized and employed as microwave absorbing materials. The mentioned materials are usually designed to solve protection against electromagnetic interference in wireless communication systems and high frequency circuit mechanisms. In this study the performance of three various polystyrene (PS) nanocomposites containing: semi-conductor zinc oxide, non-metallic conductive graphene oxide and magnetic Fe_3O_4 were compared. The fillers type was selected as variable parameter and its influence on the electromagnetic wave absorption and reflection loss (RL) amount was investigated. The scanning electron microscopy (SEM) was used in morphological and particle size study of the nanocomposites. The electromagnetic wave absorption properties of nanocomposites were studied and compared using a vector network analyzer (frequency range of 5-8 GHz). The results indicate that at the same preparation conditions the polystyrene/graphene oxide nanocomposites have higher absorption compared with others.

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INTRODUCTION

In recent years, extensive research has been devoted to study the microwave absorbing materials, which are used in electromagnetic interference protection, local area network, wireless communication, radar stealth technology and medical applications and these studies suggest that some experimental composites can obviously absorb the microwave radiation [1-3]. Facile preparation and variety of polymeric composites lead to development of electromagnetic absorbents. The electromagnetic interference (EMI) has resulted in a new kind of pollution, and electromagnetic radiation also remains a key issue to be solved. The electromagnetic waves interference caused by these waves should be considered as a serious matter and the demand for preparing and developing new electromagnetic wave absorbing materials has increased [4-5]. Commonly, the intrinsic electromagnetic properties such as frequency, dielectric constant, magnetic permeability, conductivity and thickness determine the materials electromagnetic absorption properties. However, the complexity of electromagnetic waves propagation in materials structure limits the influence analysis of each parameter on the absorption performance.

Recently, attention to polymeric

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nanocomposites has gained a great extent as they present new opportunities to provide superior properties in comparison to pure polymeric materials.

Materials with electromagnetic wave absorbing properties are used not only in military but also in industrial applications [6-10]. Absorbers with superior performance, small thickness, lighter weight, proper heat resistance, broader absorption band and low cost are suitable in practical application.

Transforming the magnetic and electrical energy of reflecting wave into heat can be take place in microwave absorbents. The loss characteristics lead to damping and heat loss when microwaves penetrate into the absorbent [9].

Polymer matrix including magnetic materials or pure dielectric can be a suitable candidate for use in microwave absorbing mediums [11, 12].

Some parameters for express of microwave absorbents properties are as follow:

1. Dielectric loss $tan\delta_e = \frac{\varepsilon''}{\varepsilon'}$

2. Complex permeability $\mu = \mu' - j\mu''$

3. Complex permittivity $\varepsilon = \varepsilon' - j\varepsilon''$

4. Magnetic loss $\tan\delta_m = \frac{\mu''}{\mu'}$

Suitable absorbent properties can be achieved by higher amounts of complex permeability (μ'') , complex permittivity (ε''),$\tan\delta_m$ and $\tan\delta_e$[12].

Some structures with high permittivity and conductivity, such as aluminum and copper and their composites are suitable candidates as shielding structures unto electromagnetic waves, but some problems such as facile corrosion and high weight restrict their applications as shielding materials.

Recently, composite structures microwave absorbers with high chemical stability and wide bandwidth as shielding materials have been studied intensively. Due to the uniform and homogeneous properties of nanostructure materials, they can be used as suitable structures in preparation of the microwave absorbent materials.

L. Wang et al. [13] investigated microwave absorption properties of a carbon nanotubes and zinc oxide mixture which were homogeneously dispersed in a paraffin matrix and maximum reflection loss (RL) -36/5 dB was at 12.29 GHz. J. Liuet et al. [8] studied the properties of Fe_3O_4 covered hollow glass spheres as an electromagnetic wave absorber in frequency range of 13 GHz and -21.5 dB. A graphene oxide sample which was covered with Ni-Co-Fe-P was studied by W. Yang et al. [14]. In frequency of 6.9 GHz, the maximum reflection loss was -12 dB. X. Tang and K.A. Hu prepared ZnO/barium ferrite-epoxy composite as an electromagnetic wave absorbent. The maximum reflection loss (-17.5 dB) occurs at the frequency of 8.5 GHz [15]. Also, a rubber containing Mn Zn ferrite radar was fabricated by A.M. Gaman et al. [16] with high amount radar absorption of -37.2 dB at 11 GHz. Nanocomposite Fe_3O_4 / flower like ZnO with a noticeable loss of -14.95 dB at 11 GHz [17] was prepared (W. Fu et al). G. Shen et al. was reported an epoxy/ferrite microwave absorbent nanocomposite with an electromagnetic loss of -12.9 dB at 15.45 GHz [18, 19].

In this paper magnetite, graphene oxide and zinc oxide were used as filler in preparation of PS nanocomposites. The performance of nanocomposites was examined to study and compare the influence of nanoparticles type in polymeric matrix on electromagnetic wave absorption.

MATERIALS AND METHODS

Bovin liver Catalase (Sigma) was dissolved in deionized water and stored at less than 4°C. H_2O_2 was purchased from Sigma Aldrich Co, which was used as catalase substrate, was dissolved in sodium phosphate buffer (50 mM). Effectors were suspended in deionized water and used in different concentrations. Nanoparticles were obtained from and sigma, respectively. All solutions were prepared daily and used immediately.A vector network analyzer (HP 8410C2) in frequency range of 5-8 GHz was employed for reflection loss measurements. Also, the SEM (SEM, XL30, Philips) was used for study of composites morphology.

The polystyrene (GPPS-1540) was provided from Tabriz petrochemical company. Graphene oxide, ZnO and Fe_3O_4 nanostructures were prepared and used in this project for preparation of nanocomposites.

Synthesis of Fe_3O_4

0.002 mol of $Fe(NO_3)_3.9H_2O$ and SDS were dissolved in distilled water. $FeCl_2$ (0.001 mol) was then added to the solution. Next, 50 mL of NaOH

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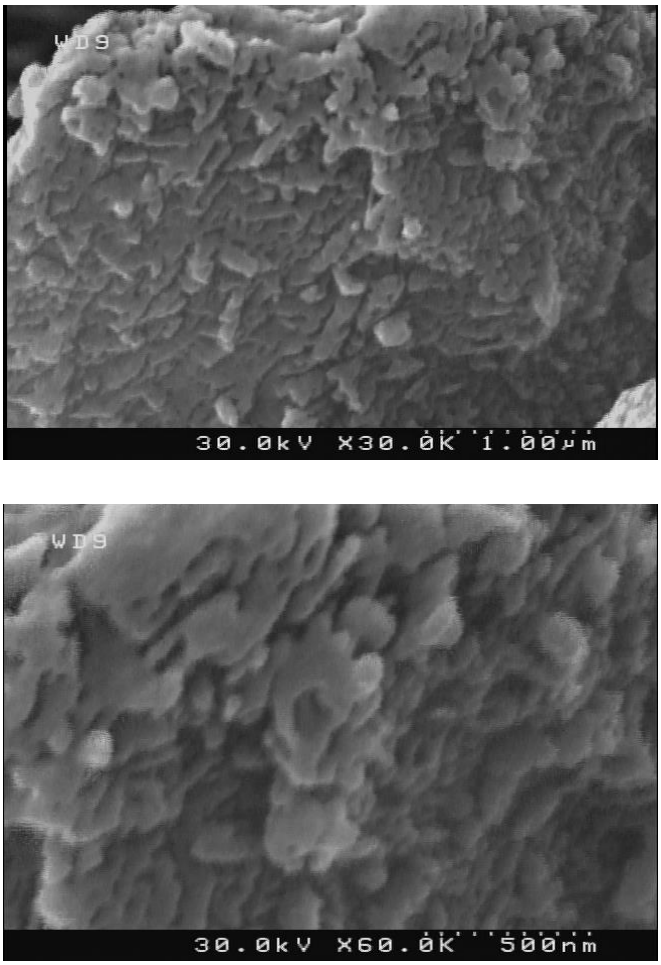

Fig. 1. SEM images of Fe_3O_4 nanoparticles prepared by NaOH addition at 250 ml of water

(or ammonia) solution 1 M was slowly added to the solution. The formation of Fe_3O_4 was confirmed by a black precipitate in this stage. The precipitate of magnetite is then centrifuged, rinsed with distilled water and dried in 35 ◦C.

Synthesis of zinc oxide

1.25 gr $Zn(NO_3)_2{\cdot}6H_2O$ and 1 gr Cetyl trimethylammonium bromide (CTAB) were dissolved in H_2O. Then, with vigorous stirring the ammonia (or ethylene diamine) solution (0.5 M) was slowly added into the above solution for 18 min. The obtained material was heated (54 ◦C) for 30 min and was centrifuged and washed with deionized water, and dried (for 18 hours) at 72◦C in a vacuum dryer.

Toluene was used for preparation of polystyrene solution (16 wt%). Then, each nanostructure (zinc oxide, magnetite and graphene oxide) was dispersed (8%) in a container via a mixer. The dispersed nanostructures were added to polymeric solution and it was placed in a stirrer under mixing rate of 10000 rpm.

A glassy plate was employed for formation of polystyrene films. In order to complete removal of toluene, the polystyrene films were grinded and poured in to screw extruder at 170 ˚C with a speed of 35 rpm. A manual 5 tons hot-press was used to compact the materials of extruder output.

RESULTS AND DISCUSSION

Materials characterization

The effect of concentration on the size and shape of Fe_3O_4 was also studied and the obtained results (Fig. 1a and 1b) confirmed that by dilution of solvent from 150 to 250 ml the nanoparticles size of 73 nm can be achieved.

Fig. 2a and 2b show the SEM images of

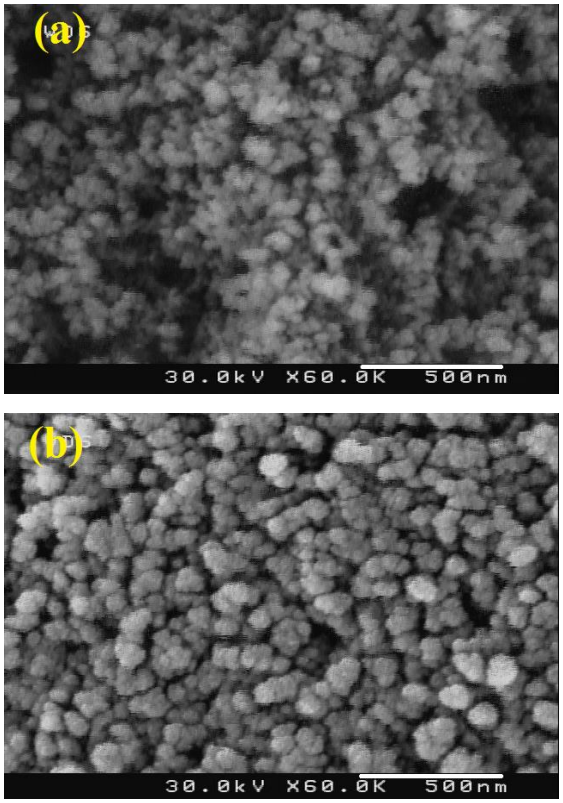

Fig. 2. SEM images of Fe_3O_4 nanoparticles, prepared by (a) NH_3 addition (b) NaOH addition

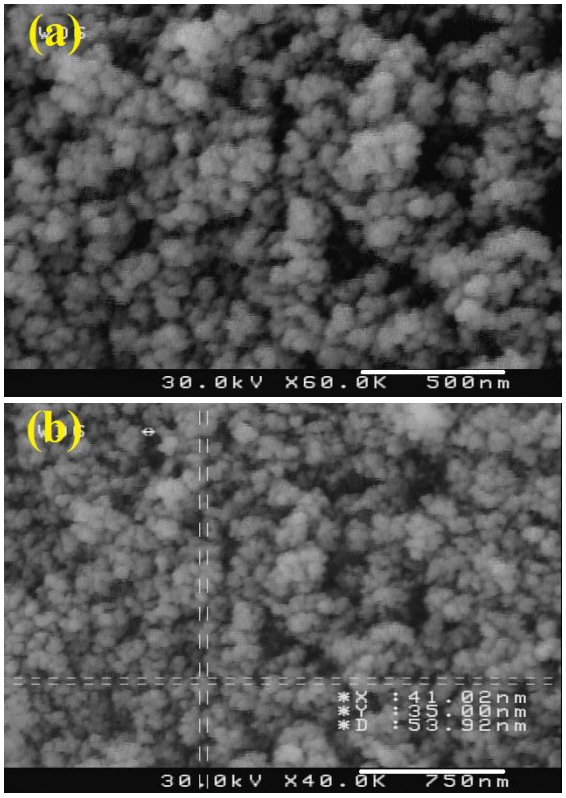

Fig. 3. SEM images of ZnO nanoparticles prepared by (a,b) NH_3 addition

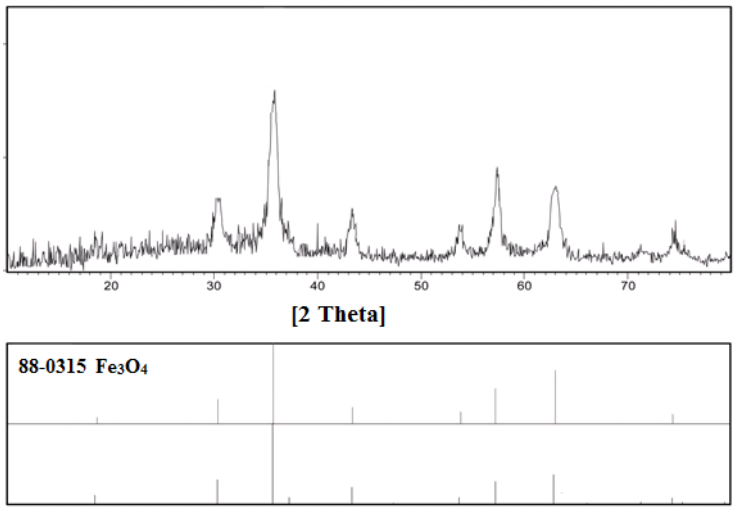

Fig. 4. XRD pattern of magnetite nanoparticles

Fe_3O_4 nanoparticles prepared by NaOH and NH_3 addition. The images indicate that in both case the magnetite nanostructures with average diameter size less than 100 nm were obtained.

Fig. 3a and 3b illustrate the scanning electron microscopy images of ZnO nanoparticles prepared by ammonia addition. The average size of 52 nm was obtained for prepared nanostructures.

XRD pattern of magnetite is shown in Fig. 4. The ferrite with cubic phase (JCPDS No. 88-0315)

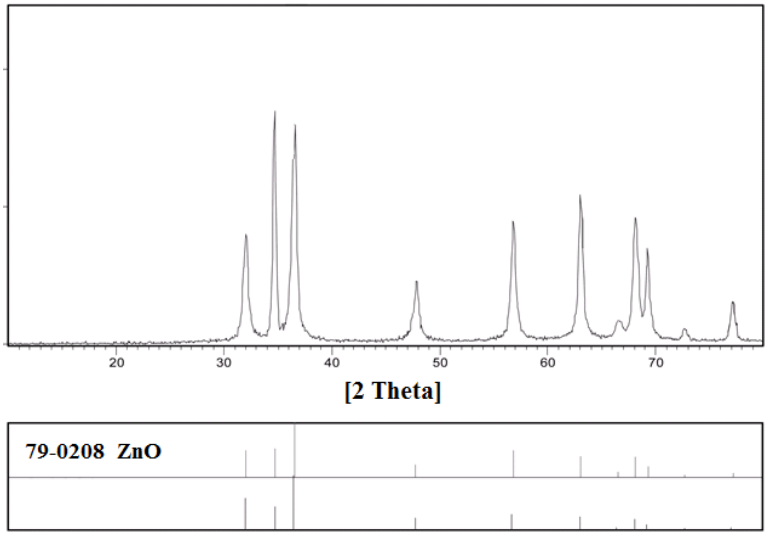

Fig. 5. XRD pattern of zinc oxide nanoparticles

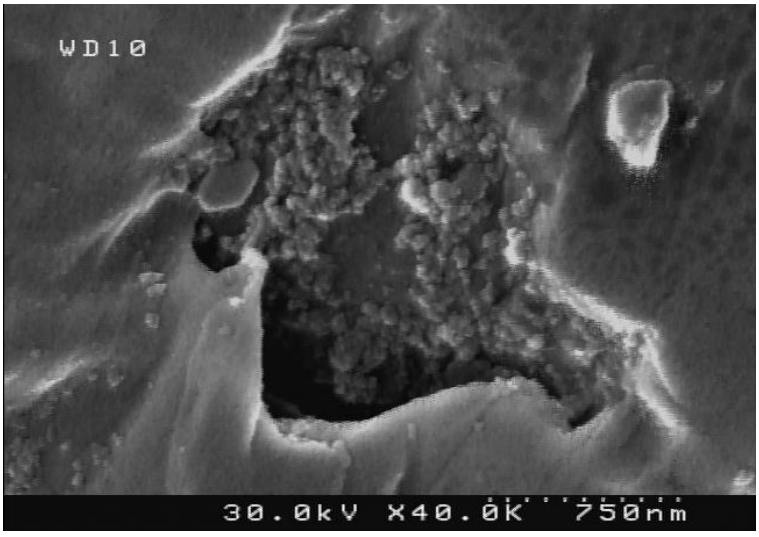

Fig. 6. SEM images of prepared nanocomposite (PS/ZnO+ Graphene oxide)

and space group of Fd-3m can be identified in mentioned pattern.

Also, XRD pattern of zinc oxide nanostructures is illustrated in Fig. 5. ZnO with Hexagonal phase (JCPDS No. 72-0208) and space group of P63mc can be approved in mentioned pattern.

The scanning electron microscopy image of nanocomposite is shown in Fig. 6. The SEM image of PS/ZnO/ Graphene oxide nanocomposite confirms the presence of additives and as expected a little agglomeration in the polymeric matrix can be seen.

Also, the results indicate that in all conditions nanostructures with mediocre size less than 100 nm were obtained.

Reflection loss and microwave absorption amounts of nanocomposites

Equations 1and 2 are used to calculate the absorption properties of single layer absorbers (Fig. 7) with various thicknesses and a metal surface at the back of each sample (based on transmission line theory):

$$RL(db) = 20 \log \left| \frac{Z_{in} - 1}{Z_{in} + 1} \right| \quad (1)$$

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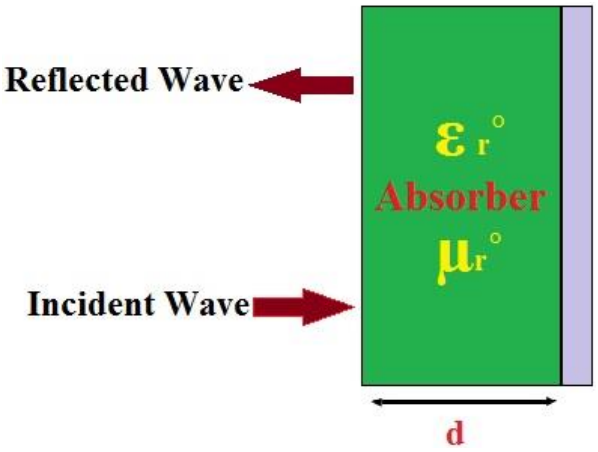

Fig. 7. Single layer absorbent

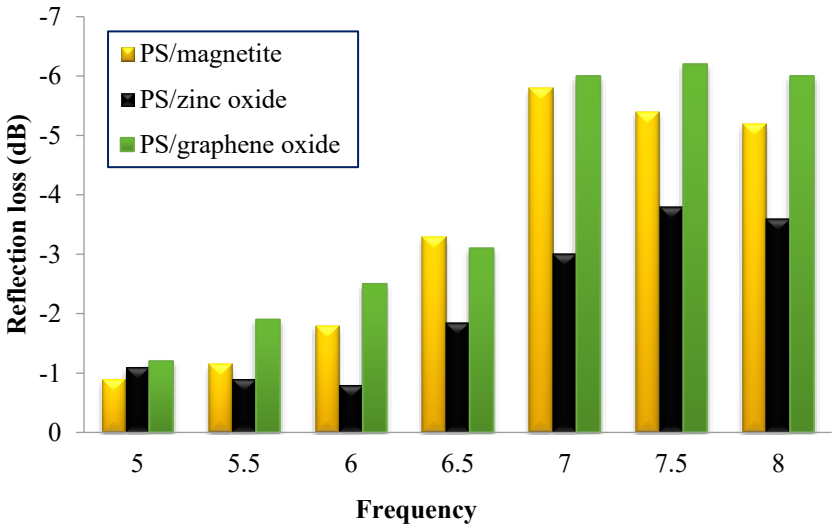

Fig. 8. Reflection loss for the prepared nanocomposites (frequency range: 5 to 8 GHz)

$$Z_{in} = \sqrt{\frac{\mu_r}{\varepsilon_r}} \tan h\left[j\left(\frac{2\pi f d}{c}\right)\sqrt{\mu_r .\varepsilon_r} \right] \quad (2)$$

Which, $\mu_r = \mu' - j\mu''$ and $\varepsilon_r = \varepsilon' - j\varepsilon''$ are the complex permeability and complex permittivity of samples, Z_{in} is the normalized input impedance relative to the free space impedance, c is the speed of light, d is the thickness of absorber and f is the frequency of electromagnetic wave in free space. The perfect results of absorption properties is achieved at Z_{in}= 1 (impedance matching reservation). The parameters including: ε',ε'',μ', μ'', f and d determine the impedance matching reservation. In a certain thickness and frequency the amount of RL can be easily determined using ε_r and μ_r [20-22].

For example, at RL equal to -20 dB, 99% of the wave is absorbed by the absorber and if this amount decreases to -10 dB, the absorbent amount will be 90% [23].

Fig. 8 shows the RL of prepared nanocomposites at frequency range of 5 to 8 GHz and homogenizer speed of 10000 rpm. It can be found that at the same preparation conditions the polystyrene/ graphene oxide nanocomposites have higher absorption compared with the PS/ZnO and PS/Fe_3O_4 nanocomposites. The inherent high reflection loss and surface structure of graphene

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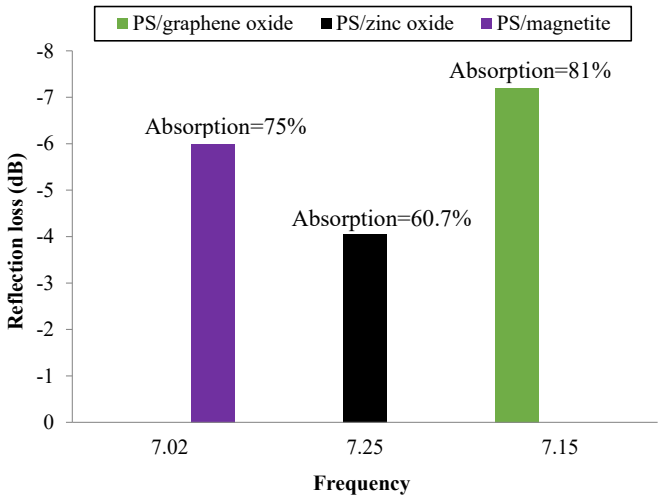

Fig. 9. Maximum reflection loss and absorption percentage of the prepared nanocomposites

oxide nanostructure are the logical reasons for these obtained results.

The maximum reflection loss and absorption amounts of prepared samples are presented in Fig. 9.

CONCLUSIONS

In this study some nanocomposites (PS/Fe_3O_4, PS/ZnO and PS/graphene oxide) were prepared and their reflection loss was investigated. The prepared nanocomposite samples were able to absorb the certain amounts of electromagnetic waves and it is worth noting that various nanocomposites have different absorption intensity. The obtained results reveal that the absorption band widths were increased as a result of suitable dispersion of nanostructures in polymeric matrix.

PS/graphene oxide nanocomposite has higher absorption compared with the PS/Fe_3O_4 and PS/ZnO nanocomposites. In the identical conditions a considerable amount (about 81%) of wave energy is absorbed by graphene oxide nanocomposite.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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