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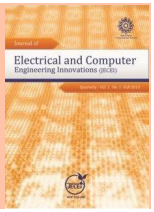
Journal of Electrical and Computer Engineering Innovations

JECEI, Vol. 5, No. 1, 2017

Regular Paper



Flexible Radar Absorbing Nanocomposites Based on Co-ferrite/Nano Carbon/polymeric Epoxy Resin

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ARTICLE INFO

ARTICLE HISTORY:
Received 3 July 2017
Accepted 16 July 2017

KEYWORDS:
Radar wave absorption
Flexible wave absorber
Absorbing nanocomposites
$CoFe_2O_4$ nanoparticles
Nanocarbon

ABSTRACT

In this research work, cobalt-ferrite ($CoFe_2O_4$) nanoparticles were synthesized by a simple, general sol-gel auto-combustion method. For this study, electromagnetic (EM) wave absorbing coatings with different weight fractions of nano-carbon and $CoFe_2O_4$ (which, arises from both dielectric and magnetic contributions) and polymeric epoxy resin were prepared and their characteristics were fully investigated. In this research, the physical properties of current products have been improved drastically. Values of reflection loss (RL) below -5dB can be obtained at the frequency range of 8-12 GHz for the composite with 1%wt nano-carbon and 59%wt $CoFe_2O_4$. As the weight fraction of nano-carbon in the composites is increased, the minimum reflection loss is reduced with a matching thickness of 1mm. This investigation concludes that hybrid EM absorbents in the form of paints, consisting of nano-sized $CoFe_2O_4$ and nano-carbon show excellent broad bandwidths of absorption. The structure, morphology and absorption properties are studied by X-ray diffraction (XRD), scanning electron microscopy (SEM) and vector network analyzer (VNA).

1. INTRODUCTION

Recently, radar absorbing materials have been extensively studied for their potential applications in military platforms. Magnetic materials continue to play a leading role in the investigation and application of radar absorbing materials. An "ideal" microwave absorbing material offers various advantages such as low thickness, low density, wide bandwidth, and flexibility [1]. According to the principle of impedance matching, when the permeability of a material is equal to its permittivity, there is no reflection and the electromagnetic wave absorption effect is the best [6]. As a result, materials with high permittivity and permeability are chosen to act as EM wave absorbers. Nevertheless, the reflection part of the waves is relatively large for a material with a too high permittivity-permeability.

Hence, it is suggested to choose a proper permittivity-permeability, as needed. Among these materials, magnetic nanoparticles of spinel ferrites are of great interest in fundamental sciences, especially for addressing the fundamental relationships between magnetic properties and their crystal chemistry and structure [2]. Cobalt ferrite ($CoFe_2O_4$) is a well-known hard magnetic material with a high coercivity (Hc) and moderate saturation magnetization (Ms). These properties, along with their great physical and chemical stability, make $CoFe_2O_4$ nanoparticles a suitable not only as an EM absorbent, but also for magnetic recording applications such as audio and videotapes, high density digital recording disks, etc. [3].

Large-scale applications of ferrites with small particles and tailoring of specific properties have prompted the development of widely used chemical

methods, including co, sol-gel [4], mechanical alloying [5] and precipitation for the fabrication of stoichiometric and chemically pure spinel ferrite nanoparticles. Among these methods, sol-gel auto-combustion method has attracted much attention due to its inherent advantages of low processing temperature and homogeneous reactant distribution and the products obtained by this method exhibit high crystalline quality and narrow size distribution. Bhattacharya, et al., (2012), investigated the EM behavior of MWCNT based nanocomposites in the X-band region [7]. Omar A. et al., (2012) studied the Dielectric and Microwave Properties of Graphene nanoplatelets /Carbon Black filled Composites [8]. Vinayasree, et al., (2012) investigated the single-layer microwave absorber based on strontium ferrite/carbon black/nitrile rubber, the result of which indicates that absorbing layer with a total thickness of 6.5 mm, reflection losses just <-5 dB over the frequency range from 8 to 11 GHz could be achieved [9]. Thus, both nanocarbon and Co-ferrite nanoparticles are good candidates for fabricating radar absorbing materials (RAMs). This paper investigates the microwave absorption properties of the composites consisting of nanocarbon and Co-ferrite nanoparticles with a thickness of 1mm, at frequency range of 8-12 GHz, in an attempt to develop a broad absorption bandwidth over the frequency range concerned. Values of Experimental absorption were calculated using the following equation:

$$P = (1\text{-}Pr\ /P_0) \times 100 \quad (1)$$

where P_r and P_0 are the reflected and incident radiation powers, respectively. The energy depletion mechanism mainly includes dielectric loss and magnetic loss.

2. EXPERIMENTAL

A. Preparation of cobalt ferrite powders

Carbon and cobalt ferrite nanopowders were used as the dielectric and magnetic fillers for producing the microwave absorbers. Nanocarbon with an average diameter of around 20-30 nm was purchased from commercial company (US Research Nanomaterials). Nano crystalline powders of $CoFe_2O_4$ were prepared by sol–gel auto-ignition method. The A.R. Grade citric acid ($C_6H_8O_7 \cdot H_2O$), Cobalt nitrate Co $(NO_3)_2.6H_2O$ and $Fe(NO_3)_3.9H_2O$ were used as the starting materials. Reaction procedure was carried out in the air atmosphere without the protection of the inert gases. The molar ratio of metal nitrates to citric acid was taken as 1:1. The metal nitrates were dissolved together in a minimum amount of double distilled water to get a clear solution. An aqueous solution of citric acid was mixed with metal nitrates solution, then ammonia solution was slowly added to adjust the pH to 7. The mixed solution was kept on a hot plate with continuous stirring at 90°C. During evaporation, the solution became viscous and finally formed a very viscous brown gel. When finally, all water molecules were removed from the mixture, the viscous gel began frothing. After few minutes, the gel automatically ignited and burnt with glowing flints. The decomposition reaction would not stop before the whole citrate complex was consumed. The auto-ignition was completed within a minute, yielding the brown-colored ashes termed as a precursor. The as-prepared powders of all the samples were heat treated at 900 °C for 2 hours to get the final product.

B. Preparation of composites

The samples for microwave absorption measurement were prepared by thoroughly mixing the absorber fillers (nanocarbon and Co-ferrite nanoparticle) with epoxy resin. Aluminum substrates with a standard size of (22.8×10.1×1 mm^3) were initially washed with pure water, then with acetone and finally dried. Five specimens with nanocarbon: Co-ferrite ratios of 1:59, 2:58, 3:57, 4:56 and 5:55, were prepared and were marked as S_1, S_2, S_3, S_4 and S_5. The carbon and Co-ferrite nanoparticles were dispersed in ethanol solution using an ultrasonic bath at room temperature for about 10 min.

After addition of epoxy resin and hardener (50:1) to the mixture, it was uniformly mixed and then applied on the Al substrates and cured at 40°C. The thickness of paints was kept constant at 1mm. Fig. 1(a), shows the sample of S_1 and its flexibility is illustrated by Fig. 1(b).

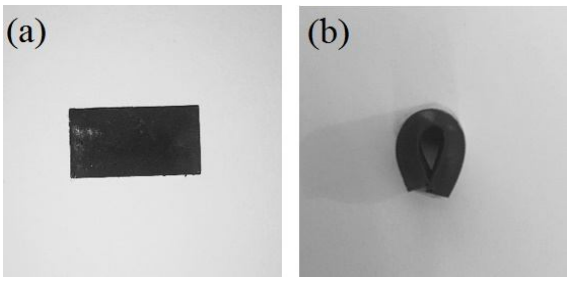

Figure 1: (a,b): The sample of S_1 and its flexibility.

C. Characterization

Phase analysis of the products was performed using a powder X-ray diffraction (XRD) technique. Surface morphology of the synthesized nanoparticles and carbon were studied using a scanning electron microscopy (SEM; Model Mira3 Tescan Czech Republic). For studying the EM absorption of the specimens, reflection/absorption measurements were performed using an HP 8510C vector network analyzer (VNA).

3. Results and Discussion

A. Microstructural analysis and SEM morphology

Fig. 2, indicates the XRD patterns of as-prepared $CoFe_2O_4$ powders.

The observed diffraction peaks of the product are perfectly indexed to an inverse cubic spinel phase (card No. 01-077-0426).

The presence of (220), (311), (400), (511), (440), (533) and (622) in the XRD patterns are in accordance with the cubic structure. The SEM micrographs of $CoFe_2O_4$ and nano carbon are shown in Figs. 3 and 4, respectively.

The $CoFe_2O_4$ powder was found to be polyhedron in shape (Fig. 3), with an average particle size of <200 nm. Fig. 4 illustrates the average diameter of the nano-carbon which is 20 to 30 nm.

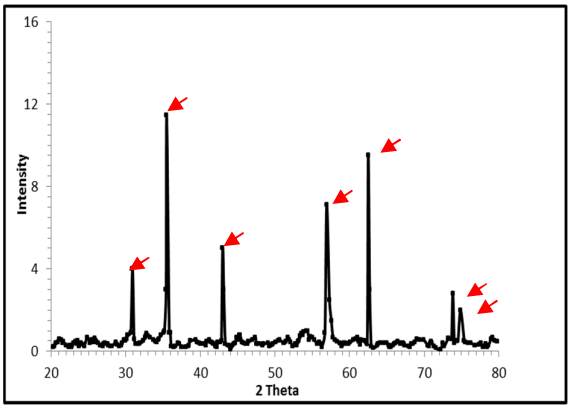

Figure 2: XRD patterns of the $CoFe_2O_4$ nanoparticles.

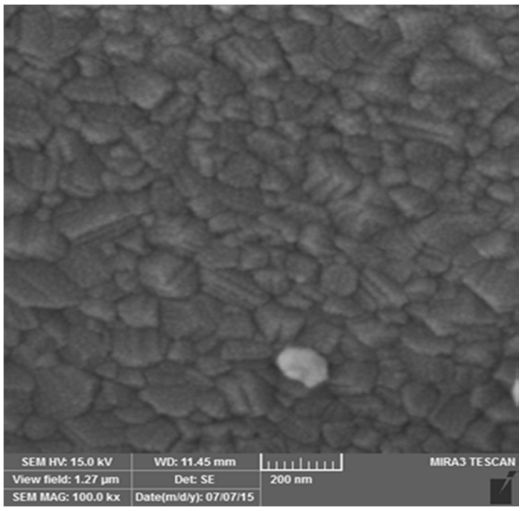

Figure 3: SEM images of the $CoFe_2O_4$ nanoparticles.

B. Reflection loss properties

Fig. 5, illustrates variation in the RL with frequency, in the paints with different $CoFe_2O_4$ content in the frequency range of 8-12 GHz. RL values of <-4 dB (over 60% microwave absorption) are obtained for most of the paints with a thickness of 1mm. The detailed parameters are summarized in Table 1.

The minimum RL value of paints S_1-S_5 are, -11.71 dB at 10.19 GHz, -11.78 dB at 11.34GHz, -10.32 dB at 11.48 GHz, -8.37 dB at 10.21 GHz and -7.21 dB at 11.38 GHz, respectively.

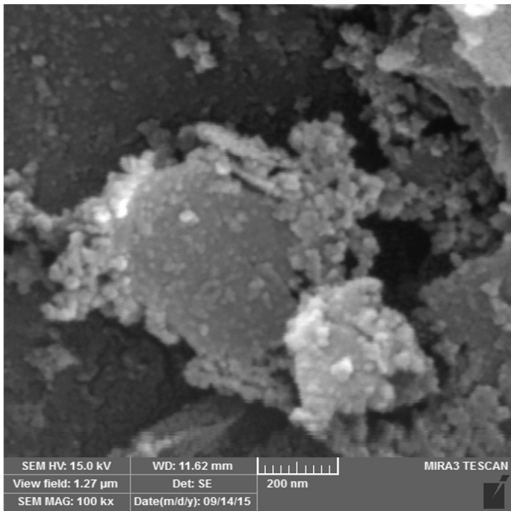

Figure 4: SEM images of the nano carbon.

4. Conclusion

In summary, carbon and Co-ferrite nanoparticles were used to fabricate EM wave absorbing paints, with a thickness of 1mm.

The microwave absorption properties of nano carbon /$CoFe_2O_4$ paints have been investigated in the frequency range of 8-12 GHz. The optimal RL reaches to -11.71 dB at 10.9 GHz with 1wt% nano carbon and 59wt% Co-ferrite.

In this composition, due to a better cooperative interaction between nano carbon and $CoFe_2O_4$, which, arises from both dielectric and magnetic contributions, desirable EM absorption properties were obtained.

As a conclusion, the microwave absorbing properties, and the absorbing bandwidth of the nanocomposites can be easily manipulated by changing the filler concentration and thickness of the sample. Therefore, this absorbing paint is an effective hybrid material for broadening the absorbing bandwidth and meeting the requirements of broadband RAMs.

It is important to mention that, Co-ferrite and carbon nanoparticles are magnetic and dielectric absorbers and the coefficients of permittivity and permeability of S_1 are the most appropriate values.

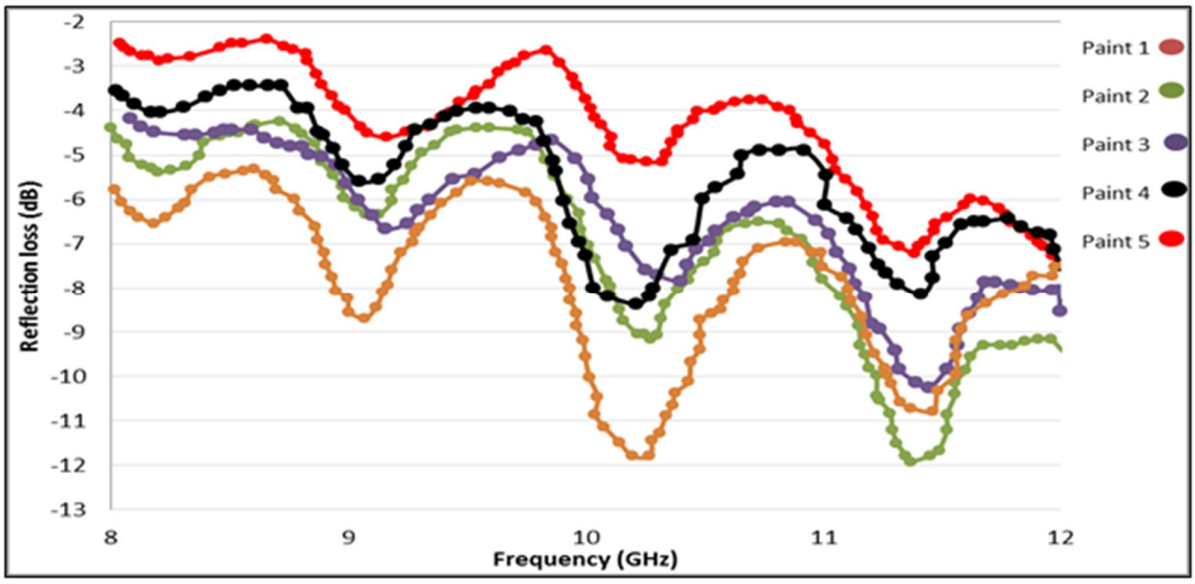

Figure 5: Reflection loss (wave absorption) of the coatings with different filler content.

TABLE 1
ELECTROMAGNETIC WAVE ABSORPTION PARAMETERS OF NANO CARBON / CO-FERRITE PAINTS

Composites nanocarbon: Co-ferrite	Bandwidth(GHz) RL <-4 dB	Maximum RL (dB)	Frequency (GHz) (maximum RL)
Paint1: S_1 (1:59)	8-12	-11.75	10.19
Paint2: S_2 (2:58)	8-12	-11.78	11.34
Paint3: S_3 (3:57)	8-12	-10.32	11.48
Paint4: S_4 (4:56)	8.7-12	-8.37	10.21
Paint5: S_5 (5:55)	8-12	-7.21	11.38

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BIOGRAPHIES



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How to cite this paper:

N. Rezazadeh and A. Kianvash, "Flexible radar absorbing nanocomposites based on Co-ferrite/nano Carbon/polymeric epoxy resin," *Journal of Electrical and Computer Engineering Innovations*, vol. 5, no. 1, pp. 53-57, 2017.

DOI: 10.22061/JECEI.2017.687

URL: http://jecei.srttu.edu/article_687.html