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Microwave Absorption Properties of Low Density Polyethelene-Cobalt Ferrite Nanocomposite

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***Abstract*—**Low density polyethylene (LDPE) nanocomposites with 3, 5 and 7 wt. % cobalt ferrite ($CoFe_2O_4$) nanopowder fabricated with extrusion mixing and followed up by hot press to reach compact samples. The transmission/reflection measurements were carried out with a network analyzer in the frequency range of 8-12 GHz. By increasing the percent of $CoFe_2O_4$ nanopowder, reflection loss (S_{11}) increases, while transferring loss (S_{21}) decreases. Reflectivity (R) calculations made using S_{11} and S_{21}. Increase in percent of $CoFe_2O_4$ nanopowder up to 7 wt. % in composite leaded to higher reflectivity amount, and revealed that increasing the percent of $CoFe_2O_4$ nanopowder up to 7 wt. % leads to further microwave absorption in 8-12 GHz range.

***Keywords*—**Nanocomposite, Cobalt Ferrite, Low Density Polyethylene, Microwave Absorption.

I. Introduction

MICROWAVE absorbing materials have promising applications through a wide range of industries such as aerospace, medical services, and civil industries like television image interference of high rise buildings [1]. Amongst compounds used for microwave absorption, nanoferrites because of their high specific resistance, outstanding flexibility in tailoring the magnetic properties and simplicity of preparation draw a lot of attention [2]. Among spinel ferrites, $CoFe_2O_4$ is especially interesting because of its high magnetocrystalline anisotropy, moderate saturation magnetization, high coercivity, and is a good choice for microwave absorbing utilities [3]-[5]. Cobalt ferrite nanopowder has been successfully synthesized by co-precipitation [4], hydrothermal [6], thermal hydrolysis, sol-gel, solid phase reactions [7], [8], pyrolysis methods [9], [10], and sol-gel auto combustion [11]. Among the reported methods, the sol-gel auto combustion method is an efficient and economical way to mass production of ultrafine cobalt ferrite nanopowder.

The electrical and magnetic properties of bulk ferrites are sensitive to a number of parameters such as grain size and structure, distribution of the metal cations among the lattice sites in the spinel structure and porosity. Bulk particles of cobalt ferrite exhibit an inverse spinel structure with one half of the Fe^{3+} ions in the A sites and the remaining half of the Fe^{3+} ions and Co^{3+} ions in the b sites. Nanocrystalline cobalt ferrite particles are exhibiting interesting structural and magnetic properties as compared to their microsized counterparts [12], [13]. Though the magnetic properties of cobalt ferrite in nanoscale have been extensively investigated. Reports on the microwave absorption of nanosized cobalt ferrite and particularly composites which contain this nanoferrite, are not very abundant in literature.

In case of ferrite-polymer composites, several studies have been carried out to investigate the effect of ferrite materials and their volume fractions on microwave absorbing properties [14]-[18]. Typically, metals have been used for microwave absorption materials as they have high conductivity and dielectric permivittivity. However, metals have disadvantages such as high weight, poor processability and corrosion. Electrically conductive polymer and ferrite composites can be used as microwave absorbing materials to circumvent the disadvantages seen in metals [19]-[23].

From an economical point of view, it is important to obtain materials as fast as possible, with low energy consumption and with the best possible properties. In this study, CoFe2O4 nanopowder blended into LDPE matrix, and LDPE-based composite made to investigate its microwave absorbing properties. Here, for the first time investigation of a LDPE-based composite with nanosized $CoFe_2O_4$ particles which is made by extrusion reported.

II. Experimental

A. Preparation of Composite Samples

LDPE Grade LF0200 (supplied from Jam petrochemical Co.) and nanopowder ($CoFe_2O_4$) were used to make composite. Blending of polymer and nanopowder have been done by extrusion machine ZKS 25 at 160-180 ℃, and 3 group of granules with 3, 5 and 7 wt.% of $CoFe_2O_4$ have been made. Granules hot pressed and rectangular samples with thickness of 10 and 15 mm have been produced. Samples are denoted as C-A1 (10 mm, 3 wt.% $CoFe_2O_4$), C-A2 (10 mm, 5 wt.% $CoFe_2O_4$), C-A3 (10 mm, 7 wt.% $CoFe_2O_4$), C-B1 (15 mm, 3 wt.% $CoFe_2O_4$), C-B2 (15 mm, 5 wt.% $CoFe_2O_4$), and C-B3(15 mm, 7 wt.% $CoFe_2O_4$).

B. Characterization

Coercivity and saturation magnetization of $CoFe_2O_4$ nanopowder was measured using a vibrating sample magnetometer (Meghnatis Daghigh kavir Co., Iran) .A HP8410C network analyzer and a personal computer far data acquisition was used to make precise measurements of S-parameters of composite sample. Absorption performance of the $CoFe_2O_4$ nanopowder can be expressed by reflectivity R [19], using (1):

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$$R\ (dB) = 20\log |\Gamma| \quad (1)$$

where Γ represent the reflection coefficient and can be explained by (2) and (3). The correct choice of positive or negative sign in (2) is made by requiring $|\Gamma| \leq 1$ [20].

$$\Gamma = K \pm \sqrt{K^2 - 1} \quad (2)$$

$$K = \frac{(S_{11}^2 - S_{21}^2) + 1}{2S_{11}} \quad (3)$$

III. Results and Discussion

A. Magnetic Measurements

Magnetic measurements of $CoFe_2O_4$ nanopowder were performed using a vibrating sample magnetometer (VSM) and result of magnetic hysteresis at room temperature is shown in Fig. 1. It is known that the magnetic properties of nano-sized particles depend on the preparation method and the particle size [4]-[6].

Compared with the $CoFe_2O_4$ nanopowder prepared by other methods [4], [6] the synthesized powder in this research possess higher saturation magnetization, 77.09 emu/g, at magnetic field of 8 kOe, which might be due to its high degree of crystallization and uniform morphology. In addition, another reason for higher saturation magnetization can be because of size of nanoparticles [4], which is around 40 nm.

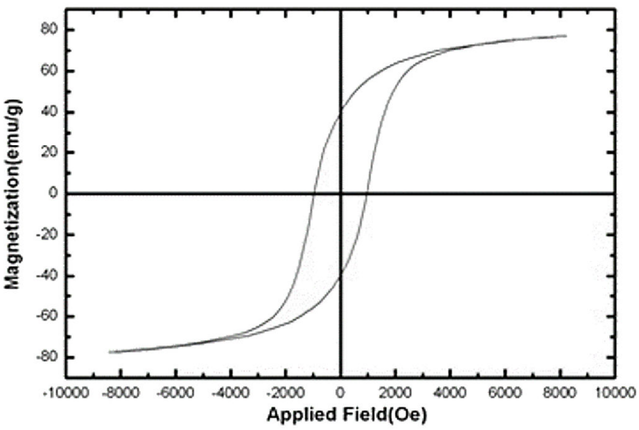

Fig. 1 Hysteresis loop of $CoFe_2O_4$ nanopowder

B. Microwave Absorption Measurement

S_{11} and S_{21} versus frequency of all samples (with 3, 5 and 7 wt. % of $CoFe_2O_4$ nanopowder), which is calculated using network analyzer, are shown in Figs. 2 and 3. In addition, reflectivity and reflection coefficient calculated using (1) and (2) and listed in Table I.

Table I shows that reflectivity and reflection coefficient are greatly dependent on $CoFe_2O_4$ nanopowder content. As can be seen in Table I and Fig. 4, the reflectivity increases with the increase in weight percent of $CoFe_2O_4$ nanopowder in composite, which means with the more $CoFe_2O_4$ nanopowder in polyethylene-based composite the absorption performance declines. It can be because of the bonds between $CoFe_2O_4$ and polymer and/or innate characters of cobalt.

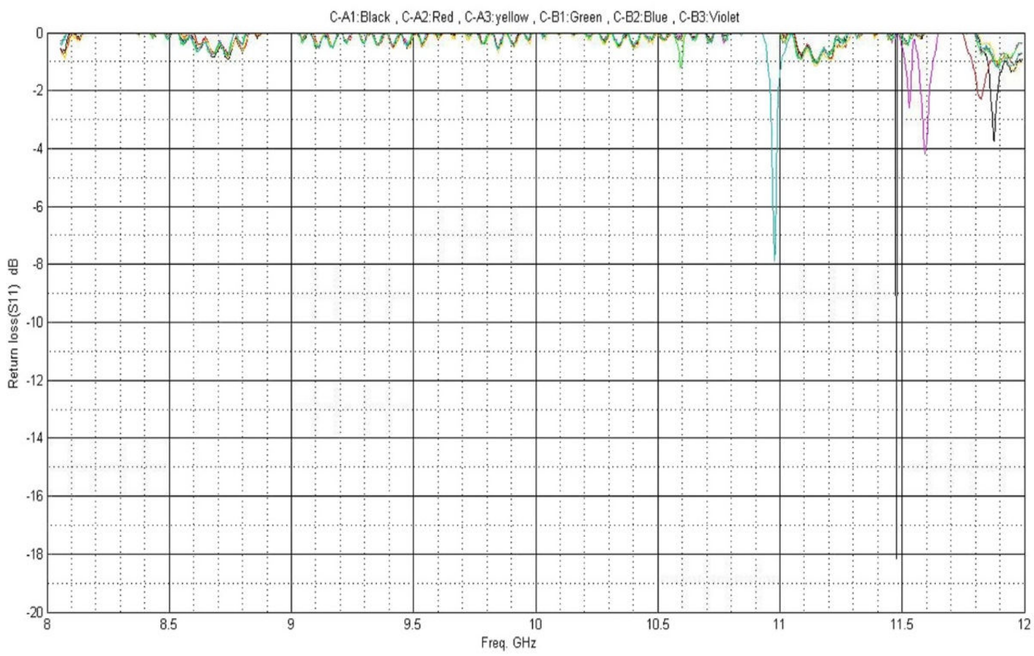

Fig. 2 S_{11} parameters of all composite samples

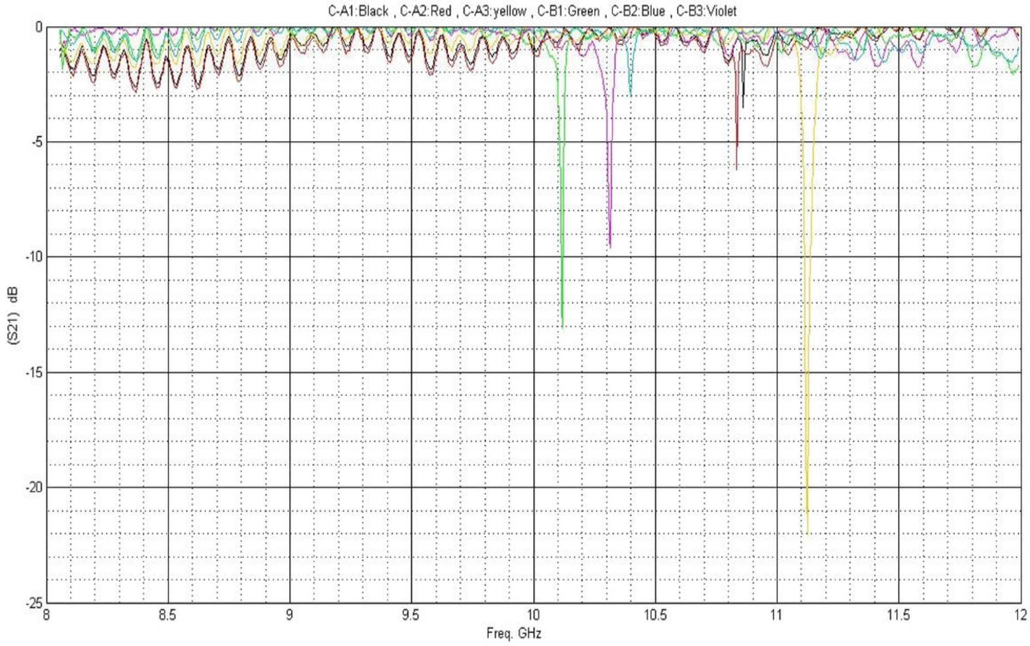

Fig. 3 S_{21} parameters of all composite samples

TABLE I
REFLECTIVITY AND REFLECTION COEFFICIENT OF ALL COMPOSITE SAMPLES

Samples	Γ (dB)	R (dB)
C-A1	-0.0757	-51.6195
C-A2	-0.0879	-48.6321
C-A3	-0.1248	-41.6235
C-B1	-0.1493	-38.0323
C-B2	-0.2080	-31.4028
C-B3	-0.4942	-14.0965

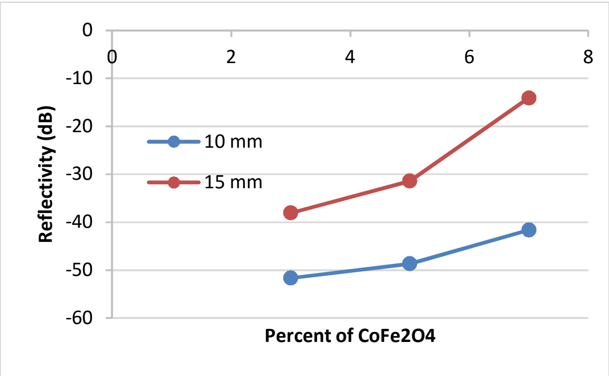

Fig. 4 Reflectivity versus percent of spinel phase

It can be concluded that composite material with a larger fraction of spinel phase is not a good choice for applications that we need less reflectivity (and also more absorption). Totally, samples showed good absorption properties in X-band, and samples with 3% of $CoFe_2O_4$ nanopowder showed the best absorption properties.

The reflectivity has great dependence on the thickness of the absorbing samples, which is seen in Fig. 4 and Table I. The reason for this phenomenon is the dimensional resonance. All samples showed good absorption ($R \leq -20$ dB) and this means absorption should be better than 99% (except sample C-B3). In other words, the reflected microwave is about 1% of incident wave, which is a very good result.

IV. CONCLUSION

In summary, saturation magnetization of $CoFe_2O_4$ nanopowder obtained using VSM, which is 77.09 emu/g. Experimental results showed that the sample with 3 wt.% $CoFe_2O_4$ and with the thickness of 10 mm have the best absorption performance and the sample with 7 wt.% $CoFe_2O_4$ and with the thickness of 15 mm have the worst absorption performance. Results showing that increasing the percent of spinel phase of $CoFe_2O_4$ nanopowder in composite have obnoxious effects on reflectivity and consequently on absorption performance.

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