

Microwave Absorption Properties of Low Density Polyethelene-Cobalt Ferrite Nanocomposite

R. Fazaeli, R. Eslami-Farsani, H. Targhagh

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 coprecipitation [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 micro-sized 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 permittivity. 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, CoFe_2O_4 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 °C, 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 for 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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$$R \text{ (dB)} = 20 \log |\Gamma| \quad (1)$$

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.

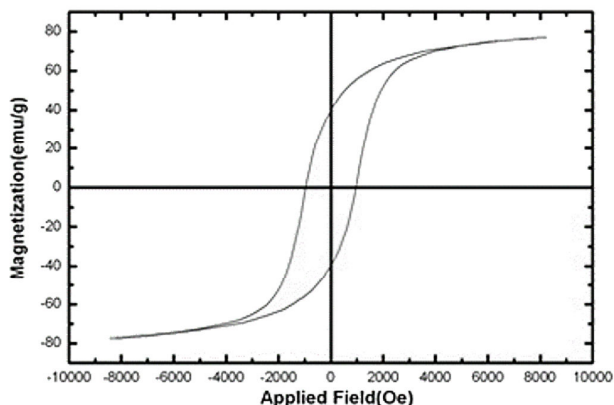


Fig. 1 Hysteresis loop of CoFe_2O_4 nanopowder

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.

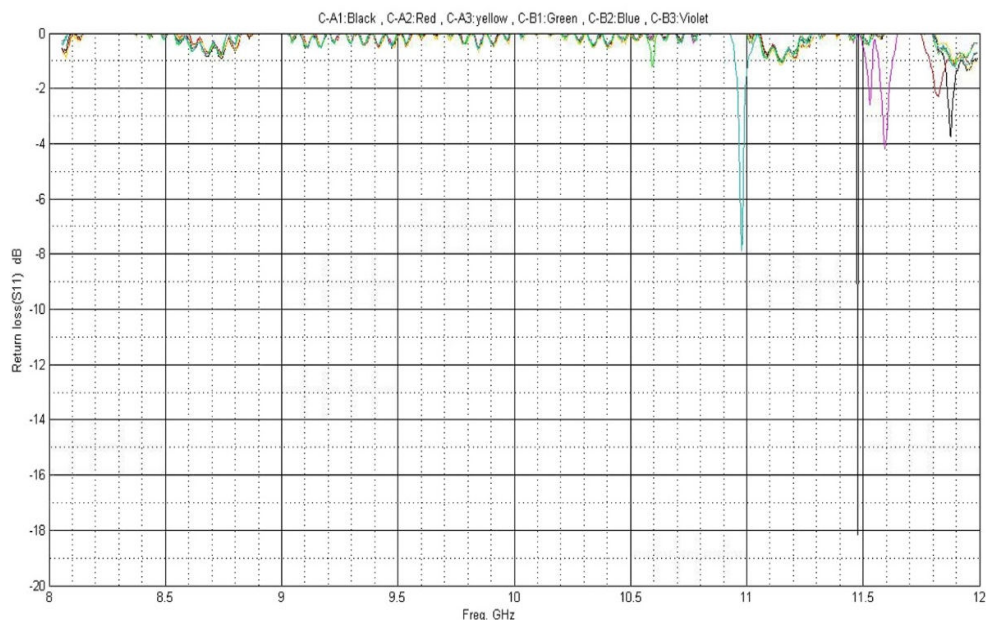
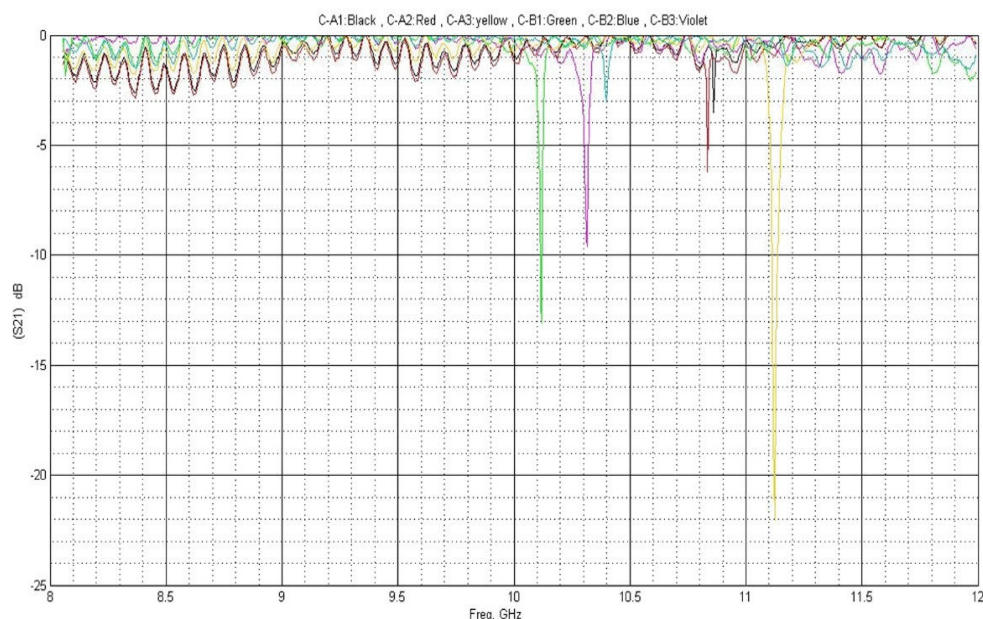


Fig. 2 S_{11} parameters of all composite samples

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

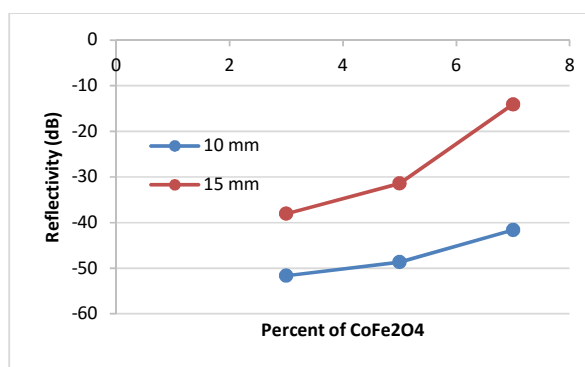


Fig. 4 Reflectivity versus percent of spinel phase

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 obvious effects on reflectivity and consequently on absorption performance.

REFERENCES

- [1] H. M. Xiao, X. M. Liu, and S. Y. Fu, "Synthesis, magnetic and microwave absorbing properties of core-shell structured $\text{MnFe}_2\text{O}_4/\text{TiO}_2$ nanocomposites", *Composites Science and Technology*, vol. 66, pp. 2003–2008, 2006.
- [2] M. Pardavi-Horvath, "Microwave applications of soft ferrites", *Journal of Magnetism and Magnetic Materials*, vol. 215–216, pp. 171–183, 2000.
- [3] P. C. Fannin, C. N. Marin, I. Malaescu, N. Stefu, P. Vlazan, S. Novanconi, P. Sfirloaga, S. Popescu, and C. Couper, "Microwave absorbent properties of nanosized cobalt ferrite powders prepared by coprecipitation and subjected to different thermal treatment", *Materials and Design*, vol. 32, pp. 1600–1604, 2011.
- [4] M. M. El-Okr, M. A. Salem, M. S. Salim, R. M. El-Okr, M. Ashoush, H. M. Talaat, "Synthesis of cobalt ferrite nano-particles and their magnetic characterization", *Journal of Magnetism and Magnetic Materials*, vol. 323, pp. 920–926, 2011.
- [5] J. G. Lee, J. Y. Park, and C. S. Kim, "Growth of ultra-fine cobalt ferrite particles by a sol-gel method and their magnetic properties", *Journal of Materials Science*, vol. 33, pp. 3965–3968, 1998.
- [6] D. Zhao, X. Wu, H. Guan, and E. Han, "Study on supercritical hydrothermal synthesis of CoFe_2O_4 nanoparticles", *Journal of Supercritical Fluids*, vol. 42, pp. 226–233, 2007.

- [7] T. S. Karpova, V. G. Vasilyev, E. V. Vladimirova, and A. P. Nosov, "Effect of synthesis on the magnetostrictive properties of CoFe_2O_4 spinel ferrite", *Bulletin of the Russian Academy of Sciences: Physics*, vol. 75, pp. 1036–1038, 2011.
- [8] E. V. Gopalan, P. A. Joy, I. A. Al-Omari, D. Sakthi Kumar, Y. Yoshida, and M. R. Anantharaman, "On the structural, magnetic and electrical properties of sol-gel derived nanosized cobalt ferrite", *Journal of Alloys and Compounds*, vol. 485, pp. 711–717, 2009.
- [9] C. H. Chen, M. H. J. Emond, E. M. Kelder, B. Meester, and J. Schoonman, "Electrostatic sol-spray deposition of nanostructured ceramic thin films", *Journal of Aerosol Science*, vol. 30, pp. 959–967, 1999.
- [10] D. R. Chen, D. Y. H. Pui, and S. L. Kaufman, "Electrospraying of conducting liquids for monodisperse aerosol generation in the 4 nm to 1.8 μm diameter range", *Journal of Aerosol Science*, vol. 26, pp. 963–977, 1995.
- [11] B. G. Tosksha, S. E. Shirsath, S. M. Patange, and K. M. Jadhav, "Structural investigations and magnetic properties of cobalt ferrite nanoparticles prepared by sol-gel auto combustion method", *Solid State Communications*, vol. 147, pp. 479–483, 2008.
- [12] B. Vishwanathan, and V. R. K. Moorthy, *Ferrite Materials: Science and Technology*, Springer Verlag, New Delhi, 1990.
- [13] N. Sivakumar, A. Narayanasamy, K. Shinoda, C. N. Chinnasamy, B. Jeyadevan, and J. M. Grenèche, "Electrical and magnetic properties of chemically derived nanocrystalline cobalt ferrite", *Journal of applied Physics*, vol. 102, pp. 013916–013918, 2007.
- [14] N. Gandhi, K. Singh, A. Ohlan, D. P. Singh, and S. K. Dhawan, "Thermal, dielectric and microwave absorption properties of polyaniline- CoFe_2O_4 nanocomposite", *Composite Science and Technology*, vol. 71, pp. 1754–1760, 2011.
- [15] D. W. Chae, and B. C. Kim, "Thermal and rheological properties of highly concentrated PET composites with ferrite nanoparticles", *Composite Science and Technology*, vol. 67, pp. 1348–1352, 2007.
- [16] P. Koskela, M. Teirikangas, A. Alastalo, J. Forsman, J. Juuti, U. Tapper, A. Auvinen, H. Seppä, H. Jantunen, and J. Jokiniemi, "Synthesis of cobalt nanoparticles to enhance magnetic permeability of metal-polymer composites", *Advanced powder Technology*, vol. 22, pp. 649–656, 2011.
- [17] R. T. Ma, H. T. Zhao, G. Zhang, "Preparation, characterization and microwave absorption properties of polyaniline/ $\text{Co}_{0.5}\text{Zn}_{0.5}\text{Fe}_2\text{O}_4$ nanocomposite", *Material Research Bulletin*, vol. 45, pp. 1064–1068, 2010.
- [18] S. P. Gairola, V. Verma, L. Kumar, M. Abdullah Dar, S. Annapoorni, and R. K. Kotnala, "Enhanced Microwave absorption properties in polyaniline and nano-ferrite composite in X-band", *Synthetic Metals*, vol. 160, pp. 2315–2318, 2010.
- [19] X. Yu, G. Lin, D. Zhang, and H. He, "An optimizing method for design of microwave absorbing materials", *Materials and Design*, vol. 27, pp. 700–705, 2006.
- [20] L. F. Chen, C. K. Ong, C. P. Neo, V. V. Vardan, and V. K. Varadan, *Microwave electronics measurement and material characterization*, John Wiley & Sons, Ltd., England, 2004.
- [21] A. Pradeep, and G. Chandrasekaran, "FTIR study of Ni, Cu and Zn substituted nano-particles of MgFe_2O_4 ", *Materials Letters*, vol. 60, pp. 371–374, 2006.
- [22] B. D. Cullity, *Elements of X-ray Diffraction*, Addison-Wesley, Reading, 1978.
- [23] V. Biju, N. Sugathan, V. Vrinda, and S. L. Salini, "Estimation of lattice strain in nanocrystalline silver from X-ray diffraction line broadening", *Journal of Materials Science*, vol. 43, pp. 1175–1179, 2008.