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Effect of zinc-nickel ferrite nanoparticles content on microwave absorbing abitility for the X-band frequency range

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Abstract

In this paper, the absorbing paint consists of carbon black/$Zn_{0.8}Ni_{0.2}Fe_2O_4$/SiO_2/epoxy (20 wt.% of carbon black constantly) had been fabricated. The effect of $Zn_{0.8}Ni_{0.2}Fe_2O_4$ content on the microwave-absorbing ability was studied for X-band frequency range. Using XRD, TEM, VSM to study the structure, morphology and magnetic properties of zinc nickel ferrite nanoparticles and zinc nickel ferrite nanoparticles covered by SiO_2 matrix. Network Analyzer (Agilent E5071C ENA series) was used to measured the reflection loss (RL) of samples with different $Zn_{0.8}Ni_{0.2}Fe_2O_4$ content (0 – 1.25 wt.%). The absorption percentage of samples increase by increasing the $Zn_{0.8}Ni_{0.2}Fe_2O_4$ content and reach to 98.4 % (1.25 wt.% $Zn_{0.8}Ni_{0.2}Fe_2O_4$).

Keywords: *Zinc-nickel ferrite, carbon black, microwave-absorbing materials, absorbing paint.*

1. Introduction

Microwave-absorbing materials are currently in high demand for civil engineering and military engineering applications. Dielectric and magnetic materials have microwave-absorbing properties. Forms of microwave-absorbing materials commonly known as sheets, bricks, paints….[1] These paints include an absorber such as carbon black, graphene, ferrite, iron carbonyl or a polymer matrix. The spinel ferrites have been choosen as absorbing materials in various forms for many years. Epoxy can play an important role in realizing these microwave absorbers with additional functionalities like elasticity for the mixture. Some works are mixture of glass fabric/epoxy and carbon black [2,3], carbon nanotubes in a matrix of strontium and nickel ferrite, composites of carbon nanotubes and polyurethane [4], iron carbonyl and carbon black in an epoxy resin/rubber matrix [5,6] The content of absorbers are 20–25 wt.% carbon black [1, 5], 60–80 wt.% ferrite [7,8] or 25–50 wt.% iron carbonyl [5, 6]. The microwave-absorbing ability depended on the absorber content and coating thickness. The thinner and lighter coating with high microwave absorption was the aim of the application.

In this study, microwave-absorbing samples were fabricated using 20 wt.% carbon black, super-paramagnetic $Zn_{0.8}Ni_{0.2}Fe_2O_4$ dispersed in SiO_2 matrix with different contents (0, 5, 15 and 25%) corresponding to 0, 0.25, 0.75, 1.25 wt%, of $Zn_{0.8}Ni_{0.2}Fe_2O_4$ and epoxy resin to test their microwave absorption at 8 – 12 GHz (X band range).

2. Materials and Method

The structure of zinc-nickel ferrite cover by SiO_2 layers samples were analysed by X-ray diffraction (XRD) using Bruker AXS D8 differactometer with Cu-Ka radiation. The morphological study was carried out by transmission electron microscope (TEM, JEOL- 1400). Magnetic measurements of samples were taken out at room temperature using vibrating sample magnetometer, (VSM, MICRO SENSE 3474-140). To study the reflection loss of samples, carbon black (20 wt.%) was mixed with different $Zn_{0.8}Ni_{0.2}Fe_2O_4$ contents and epoxy resin, hardener to form microwave-absorbing paints. Then, the paint was coated onto the steel plates (200 × 200 × 3 mm) and dried for three days. The mixture proportions was shown in Table 1. The reflection loss were measured thorough Network Analyzer (Agilent E5071C ENA series) in the frequency range of 8 –12 GHz at room temperature.

The prepared samples with $Zn_{0.8}Ni_{0.2}Fe_2O_4$ contents of 0, 5, 15 and 25 wt.% were signed as samples 1, 2, 3 and 4.

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Table 1. The four prepared samples with differents $Zn_{0.8}Ni_{0.2}Fe_2O_4/SiO_2$ content

Samples	Carbon black (wt.%)	Zinc-nickel ferrite covered by SiO_2 layers (wt.%)	Epoxy resin (wt.%)
1	20	0 (0)	80
2	20	5 (0.25)	75
3	20	15 (0.75)	65
4	20	25 (1.25)	55

The super-paramagnetic $Zn_{0.8}Ni_{0.2}Fe_2O_4$ content of the CB/$Zn_{0.8}Ni_{0.2}Fe_2O_4/SiO_2$/epoxy resin mixture is indicated in parentheses.

3. Results and Discussion

3.1 Structure analysis

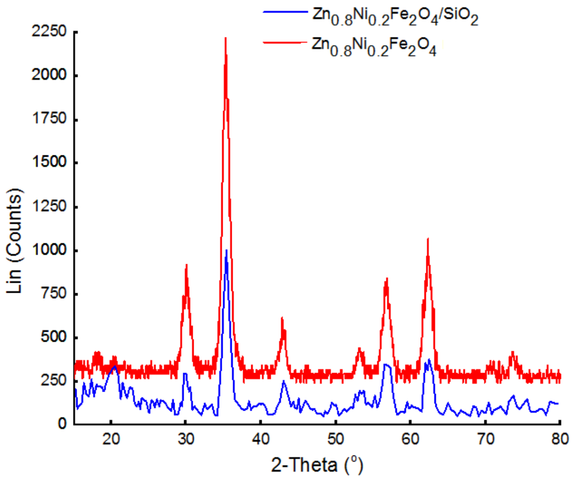

Fig. 1 XRD spectra of $Zn_{0.8}Ni_{0.2}Fe_2O_4$ and $Zn_{0.8}Ni_{0.2}Fe_2O_4/SiO_2$

The zinc nickel ferrite nanoparticles was obtained after annealing at 140^{o}C for 6 hours, all peaks (220), (311), (400), (422), (511) and (440) corresponding to zinc nickel ferrite spectrum (JCPDS 52-0277) shown in figure 1. Besides that, the XRD pattern of the $Zn_{0.8}Ni_{0.2}Fe_2O_4/SiO_2$ composite displays only five peaks corresponding to (220), (311), (400), (511) and (440) lattice planes that are less intense than those of $Zn_{0.8}Ni_{0.2}Fe_2O_4$. This could be explained by and an amorphous SiO_2 layer cover on the surface of particles.

3.2 Morphology of $Zn_{0.8}Ni_{0.2}Fe_2O_4/SiO_2$ and carbon black nanoparticles

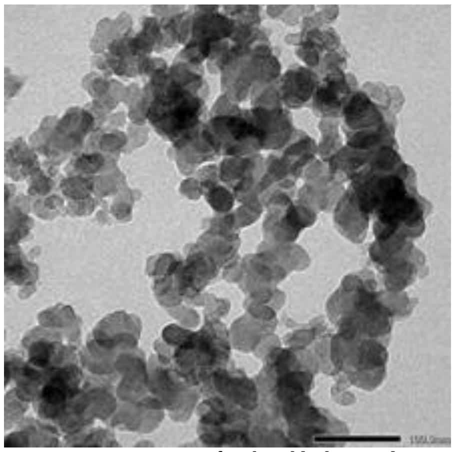

Fig.2 TEM image of carbon black particles

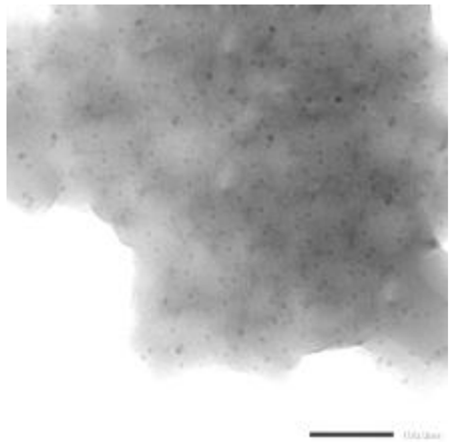

Fig. 3 TEM micrograph of zinc nickel nanoparticles dispersed into SiO_2 matrix

Figure 2 shows the average size of carbon black is around of 29 nm. The TEM image of figure 3 indicates that zinc nickel nanoparticles are dispersed into SiO_2 matrix, the avarage particles size is about 5 nm and the morphology is nearly pherical.

3.3 Magnetic properties of $Zn_{0.8}Ni_{0.2}Fe_2O_4$ and $Zn_{0.8}Ni_{0.2}Fe_2O_4/SiO_2$

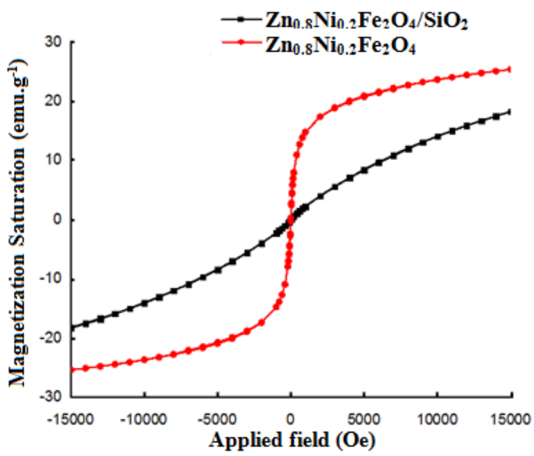

Fig. 4 Magnetisation curves of $Zn_{0.8}Ni_{0.2}Fe_2O_4$ and $Zn_{0.8}Ni_{0.2}Fe_2O_4/SiO_2$

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Table 2. Magnetic properties of $Zn_{0.8}Ni_{0.2}Fe_2O_4$ and $Zn_{0.8}Ni_{0.2}Fe_2O_4/SiO_2$ nanoparticles

Sample name	Remanent magnetisation M_r (emu.g^{-1})	Saturation magnetisation M_s (emu.g^{-1})	Coercivity Hc (Oe)
$Zn_{0.8}Ni_{0.2}Fe_2O_4$	≈ 0	25.39	≈ 0
$Zn_{0.8}Ni_{0.2}Fe_2O_4/SiO_2$	≈ 0	18.95	≈ 0

Figure 4 and table 2 show the magnetic properties of the $Zn_{0.8}Ni_{0.2}Fe_2O_4$ nanoparticles and $Zn_{0.8}Ni_{0.2}Fe_2O_4/SiO_2$. All of samples demonstrate the coercivity (H_c) and remnant magnetisation (M_r) are nearly zero, clearly show the super-paramagnetic state. The saturation magnetisation (M_s) of the $Zn_{0.8}Ni_{0.2}Fe_2O_4$ nanoparticles is 25.39 emu·g^{-1}, higher than sample of $Zn_{0.8}Ni_{0.2}Fe_2O_4/SiO_2$ which expressed only 18.95 emu·g^{-1}. The nonmagnetic SiO_2 layers is the main cause of the saturation magnetisation (M_s) decrease.

3.4 Microwave-absorbing ability of four samples for X band range (8 – 12 GHz)

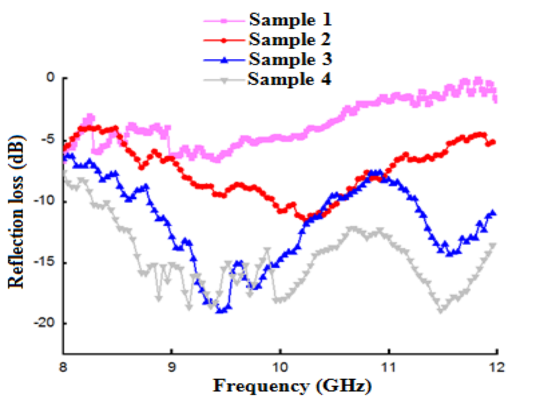

Fig. 5 Reflection loss (RL) of sample 1, 2, 3 and 4 for X-band range

Table 3. RL and absorption percentage of samples based on $Zn_{0.8}Ni_{0.2}Fe_2O_4$ in a super-paramagnetic or ferri-magnetic state

Samples	RL (dB) at 10-GHz centred frequency	Absorption percentage (%) at 10-GHz centred frequency
1	- 4.83	67.2
2	-10.85	91.8
3	-14.82	96.7
4	- 18.07	98.4

Figure 5 and table 3 indicate that measured samples exhibit the RLs and absorption percentages of sample 1, 2, 3 and 4 at the X-band centre frequency of 10 GHz are -4.83, -10.85, -14.82, -18.07 dB, corresponding to 0, 0.25, 0.75 and 1.25 wt.% $Zn_{0.8}Ni_{0.2}Fe_2O_4$ content of absorbing paint. The increase in $Zn_{0.8}Ni_{0.2}Fe_2O_4$ content led to an increase in the RL of all samples. The small content of $Zn_{0.8}Ni_{0.2}Fe_2O_4$ (0.25 wt.%) reachs to high RL (91.8%). So, the RLs of the samples at 10 GHz are almost dependent on the $Zn_{0.8}Ni_{0.2}Fe_2O_4$ content.

4. Conclusions

In sumary, the absorbing paint based on using carbon black/$Zn_{0.8}Ni_{0.2}Fe_2O_4/SiO_2$/epoxy are successfully fabricated. The effect of super-paramagnetic $Zn_{0.8}Ni_{0.2}Fe_2O_4$ content on the microwave-absorbing ability was carried out in the X-band frequency range. It found that the increase of $Zn_{0.8}Ni_{0.2}Fe_2O_4$ content (from 0 to 1.25 wt.%) led to an increase of RL. Sample 1 with no $Zn_{0.8}Ni_{0.2}Fe_2O_4$ content reach only 67.2 % of absorption percentage. However, sample 4 contained 1.25 wt.% $Zn_{0.8}Ni_{0.2}Fe_2O_4$ exhibited the high microwave absorption of 98.4% power attenuation at 10 GHz.

Acknowledgments

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