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ScienceDirect
Journal of Magnetism and Magnetic Materials 320 (2008) 864–870
Journal of magnetism and magnetic materials
www.elsevier.com/locate/jmmm

Microwave-absorbing properties of $Ni_{0.50-x}Zn_{0.50-x}Me_{2x}Fe_2O_4$ (Me = Cu, Mn, Mg) ferrite–wax composite in X-band frequencies

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Received 18 June 2006; received in revised form 17 July 2007
Available online 10 October 2007

Abstract

$Ni_{0.5-x}Zn_{0.5-x}Me_{2x}Fe_2O_4$ (Me = Cu, Mg, Mn; $x = 0.00$ and 0.10) ferrite powders were prepared by the nitrate-citrate precursor method and investigated as a radar absorbing material (RAM) in a frequency range of 8–12 GHz (X-band). The effects of Cu^{2+}, Mn^{2+} and Mg^{2+} substitution on the microwave-absorbing feature, the complex permeability (μ_r^*) and the complex permittivity (ε_r^*) were investigated. The microwave-absorbing properties were studied as a function of frequency, Me^{2+} content, and thickness of absorber. The adoption of Cu^{2+} and Mn^{2+} substitution was found to improve the microwave absorption and bandwidth, while the substitution of Mg^{2+} was found to reduce the microwave absorption in relation to non-substituted NiZn ferrite.

Keywords: Ferrite; Microwave absorber; Radar; Electromagnetic Property

1. Introduction

Since Word War II, special attention has focused on the development of new materials and microwave technology for application in the field of stealth technology. A variety of dielectric and magnetic materials has been extensively researched for use as radar absorbing materials (RAM) [1–3]. RAM are normally used in the covering of external or internal reflective surfaces of military vehicles, ships and aircraft, to reduce the radar cross section (RSC) [4,5] and thus increase their "invisibility" to radar. The choice of RAM should take into account the material's durability, mechanical resistance, weight, thickness, cost, handling and applicability. Among the materials used in such applications, ferrites exhibit an interesting behavior, absorbing energy from electromagnetic waves, and present the best relation between the absorber's performance and its final thickness. Ferrites have been used as absorbing materials in various forms, e.g., sheets, paints, films, ceramic tiles, powders, and loads in matrix composites or mixed with conducting material [6,7].

Among the spinel ferrites, NiZn ferrites have been widely utilized as electromagnetic wave absorbing materials in the VHF/UHF region [8,9]. Nevertheless, the application of NiZn ferrites as RAM in X-band frequencies requires better performance. The X-band frequency radar has been of great interest to the military sector because it allows for high resolution imaging and greater precision target identification.

To improve the attenuation and microwave absorption in the X-band, it is clear that their electromagnetic losses should be as high as possible [10]. The behavior of reflection loss and attenuation in ferrite absorbers can be characterized by means of the complex permeability ($\mu_r^* = \mu_r' - j\mu_r''$) and complex permittivity ($\varepsilon_r^* = \varepsilon_r' - j\varepsilon_r''$), which are dependent on the absorber's chemical composition.

Substituting a portion of the divalent metallic ions in NiZn ferrites can modify their electromagnetic properties, which would also lead to modifications in their microwave absorbing properties. This paper discusses the microwave absorption characteristics of $Ni_{0.50-x}Zn_{0.50-x}Me_{2x}Fe_2O_4$

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doi:10.1016/j.jmmm.2007.09.020

(Me = Cu, Mn, Mg; $x = 0.00$ and 0.10)–wax composites of a monolayer absorber. The microwave absorbing properties were studied as a function of the frequency, Me^{2+} content, and thickness of the absorber. The effects of Me^{2+} substitution on the electromagnetic properties were investigated and are also discussed here.

2. Experimental procedure

2.1. Synthesis and XRD characterization

Analytical grade metal nitrates and citric acid were used as raw materials. An appropriate amount of metal nitrates and citric acid to produce ferrite powders with their respective compositions was first dissolved in deionized water. This citric acid solution was heated to $60 \pm 5\,^{\circ}C$ for 30 min. The nitrate solution was then slowly added to the citric acid solution under constant stirring, in a molar ratio of 1:1 nitrate and citrate. The final mixed solution was concentrated at $70 \pm 5\,^{\circ}C$ until it turned into a dark red viscous liquid, which was then dried in a rotary evaporator at $80 \pm 5\,^{\circ}C$ to form a gel. To produce the ferrite powders, the dried precursor was heated at 1000 °C for 3 h in air, at a heating rate of 1 °C/min.

Powder X-ray diffraction data were collected on a Siemens D5000 X-ray diffractometer with Cu K_{α} radiation ($\lambda = 0.154178$ nm). The scanning range was 10–80° (2θ), step size = 0.02° (2θ), step time = 1 s. The data were processed for phase characterization.

2.2. Measurement

The complex scattering parameters of reflection and transmission (S^*_{11}, S^*_{21}) of a transverse electric and magnetic wave were measured in the X-band by an HP 8510B Network Analyzer. The Nicolson-Ross-Weir model [11–13] was used to determine the real and imaginary components of the complex magnetic permeability (μ^*_r) and complex magnetic permittivity (ε^*_r) from the measured values of reflected and transmitted scattering parameters. For this purpose, ferrite–wax composites containing 80% of ferrite (wt%) were prepared by homogeneously mixing the ferrite powder into a wax matrix bonded to the rectangular ($h = 10.16$ mm and $w = 22.86$ mm) waveguide board.

2.3. Microwave-absorbing properties

With regard to an electromagnetic absorbing layer terminated by a conductor (short-circuit), the microwave-absorbing properties and reflection loss (RL) can be evaluated by formulas (1) and (2), where γ is the electromagnetic propagation constant in the material, $\gamma = \alpha + \beta j = j2\pi/\lambda\sqrt{\mu^*_r\varepsilon^*_r}$, α and β are the attenuation constant and phase constant, respectively, λ is the microwave's wavelength in free space, μ^*_r is the complex permeability and ε^*_r is the complex permittivity, Z_{in} is the normalized input impedance at the absorbent surface, and t is the thickness of the absorber [14,15],

$$Z_{in} = \sqrt{\frac{\mu^*_r}{\varepsilon^*_r}}\tanh[\gamma.t], \quad (1)$$

$$\text{reflection loss (dB)} = 20\log_{10}|(Z_{in} - 1)/(Z_{in} + 1)|. \quad (2)$$

We have considered the matching condition (thickness and frequency) at the dip with a reflection loss satisfying at least $RL \leqslant -20$ dB. This means that the absorption should be better than 99%. In other words, the reflected microwave power is about 1% of incident microwave power.

3. Results

Fig. 1 shows the XRD for ferrite powders, indicating only a single, essentially cubic spinel ferrite phase, CFC. The index *hkl* is based on the JCPDS card no. 08-0234. The absence of any other impurity phase confirms that $Ni_{0.50-x}Zn_{0.50-x}Me_{2x}Fe_2O_4$ (Me = Cu, Mg, Mn; $x = 0.00$ and 0.10) ferrite can be synthesized by the citrate-nitrate method.

Fig. 2 illustrates the behavior of electromagnetic properties with frequency for all the samples in the range of 8.0–12.0 GHz. Fig. 2a represents the variation in the real part of complex permeability (μ'). From this figure, it can be seen that the substitution of Cu^{2+} and Mn^{2+} was effective in reducing the real permeability values. The figure also indicates that Mg-substituted NiZn ferrite was the only material presenting higher real permeability values than the non-substituted NiZn ferrite. Fig. 2b illustrates the variation in the imaginary part of the complex permeability (μ''), indicating that the imaginary permeability of all the samples decreased as the frequency increased. However, Mn-substituted NiZn ferrite displayed

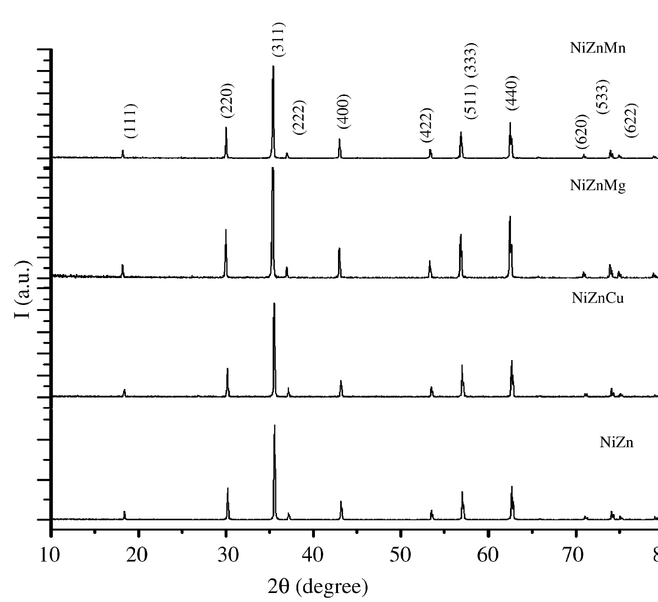

Fig. 1. XRD patterns of $Ni_{0.50-x}Zn_{0.50-x}Me_{2x}Fe_2O_4$ (Me = Cu, Mg, Mn; $x = 0.00$ and 0.10) ferrite.