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MAGNETOPOLYMERS FOR EMI SUPPRESSION IN PORTABLE AND WIRELESS ELECTRONICS

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The complex permeability spectra of ferrite–polymer composites have been measured in the frequency range 1 kHz – 1 GHz using short–circuit coaxial transmission line method and the effect of particle size and ferrite volume content was studied. The ferrite filler had the chemical composition $Ni_{0.276}Zn_{0.644}Cu_{0.08}Fe_2O_4$ and was synthesized by means of a ceramic method at 1200 °C/6 h in air. As the non–magnetic matrix, polyvinylchloride (PVC) polymer has been used. The frequency dispersion of permeability was due to a resonance of oscillating domain walls and a natural ferromagnetic resonance of precessing magnetic moments in domains. The permeability of composites seems to be strongly dependent on ferrite volume content and weakly on particle size. Based on the theoretical calculation of return loss (*RL*), the quasi–microwave absorption properties of the ferrite–polymer composites have been investigated in the frequency range concerned. In the developed single–layer EM–wave absorbers, the return loss as well as the matching thickness (d_m), matching frequency (f_m), and bandwidth for $RL \leq -15$ dB were affected by changes in ferrite particle size and volume content. The results indicate that the magnetopolymers have significant potential for quasi–microwave absorption applications in mobile electronic industry.

Keywords: complex permeability, domain wall, magnetopolymer, return loss, matching thickness, EM–wave absorber

1 INTRODUCTION

As a result of fast development of mobile communication industry, the importance of reduction of electromagnetic interference (EMI) between electromagnetic wave (EM–wave) radiating systems (mobile phones, wireless LAN systems, Bluetooth devices, Fig. 1) and devices such as LSI, CPU, etc., play a significant role.

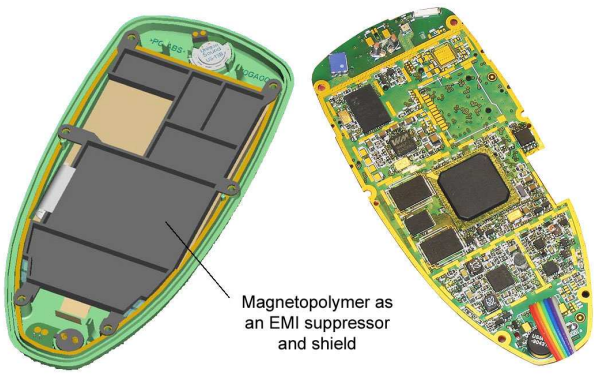

Fig. 1. View of disassembled mobile communicator and application of magnetopolymer as an EMI suppressor to block the conduction of EMI noise on printed circuit boards.

This has given a priority towards research of various materials which can be used as microwave absorbers and/or shields. Among the candidates for such applications, soft metallic magnets, polycrystalline spinel or hexagonal ferrites, and ferrite–epoxy composites [1, 2] present a kind of interesting materials. For magnetic EM–wave absorbers, the complex permeability $\mu^* = \mu' - j\mu''$ (and also complex permittivity $\varepsilon^* = \varepsilon' - j\varepsilon''$) of materials determine reflection and attenuation characteristics of absorbers. Because the matching thickness d_m is inversely proportional to a product of $f_m\mu''$ ($d_m \approx 1/f_m\mu''$) with f_m the matching frequency and the maximum μ'' value induced by natural resonance phenomenon is proportional to the ratio of saturation magnetization M_s and effective anisotropy field H_A ($\mu'' \approx M_s/H_A$), the d_m is inversely proportional to M_s. Since soft metallic magnetic materials have large M_s and the Snoek's limit is localized at a high frequency [3, 4], their μ^* value remain high over a wide frequency range. Therefore, it is possible to make thin absorbers from such kinds of materials. However, the high–frequency permeability of soft metallic magnets and also some kinds of spinel ferrites such as MnZn decreases due to the eddy current loss induced by EM–waves. For this reason, it is better to use smaller particles which are isolated by insulating non–magnetic materials, such as epoxy resin or polyvinylchloride (PVC). We have investigated ferrite–polymer composite materials based on PVC polymeric matrix and various types of ferrite fillers: NiZn, MnZn and LiZn [3–6], and have found out that the complex permeability had a characteristic frequency dispersion and was attributed to two kinds of resonance mechanisms: the resonance of vibrating domain walls and the natural ferromagnetic resonance of rotating magnetic moments in domains. In most cases, the dispersion of permeability of sintered materials (such as ferrites) was of a resonance type and changed to a relaxation type of dispersion in the case of ferrite–polymer composites. We have also studied the EM–wave absorbing properties of some NiZn ferrite – PVC polymer composites [3, 4] only as a function of ferrite content and found these materials as good candidates for single–layer absorber design.

In this work, more detailed study is carried out to investigate the effects of particle size and ferrite filler con-

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tent in composites (based on NiZnCu spinel ferrite and PVC polymeric matrix) on their complex permeability spectra and EM–wave absorption properties (using a short–circuit coaxial transmission line measurement method) in the frequency interval of 1 kHz to 1 GHz. Simple computer simulations made in the MATHCAD environment has been used to design of single–layer absorbers for EMI suppression.

2 EXPERIMENTAL

The polycrystalline NiZnCu spinel ferrite of composition $Ni_{0.276}Zn_{0.644}Cu_{0.08}Fe_2O_4$ prepared in the sintered and also powder form by a ceramic method at 1200 °C/6 h in air has been used as ferrite filler. The ferrite–polymer composites have been prepared from the ferrite powder and PVC matrix by the dry pressing method (at a temperature of 135 °C and at a pressure of about 5 MPa). Two sets of composites were made to examine the effects of the ferrite particle size and the ferrite volume content on permeability and EM–wave absorbing properties: (1) constant particle size 0–250 µm and different filler volume concentrations 10, 20, 30, 40, 50, 55 and 60 vol%, and (2) constant ferrite volume concentration 60 vol% and different particle sizes 0–25, 25–40, 40–80, 80–160 and 160–250 µm. In order to obtain complex permeability spectra, all the prepared samples were prepared in the toroidal form with an inner diameter of 3.4 mm, an outer diameter of 7 mm and a height of 3 mm. Complex permeability of sintered ferrite and composites was measured by means of a coaxial line method in the frequency range of 1 kHz to 1 GHz using two different analyzers (HP 4192A and HP 4191A).

3 THEORY OF EM–WAVE ABSORBER FOR UHF BAND

Ferrite–polymer composites are used as electromagnetic wave absorbers thanks to their losses at higher frequencies. It has been shown [3] that these losses are very useful for the construction of a thin EM–wave absorber for high frequency band in the form shown in Fig. 2.

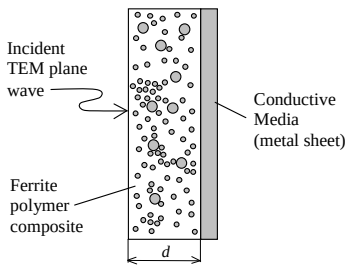

Fig. 2. The principle of an electromagnetic wave absorber.

The frequency of the incident wave and the thickness at which ferrite polymer composite material in contact with a highly conductive metal plate becomes an absorber, are called the matching frequency f_m and matching thickness d_m, respectively. One of the most important problems in this application is how small a thickness, d_m, is possible. To solve this, knowledge of the complex permeability/permittivity spectra of composite materials is required.

With respect to the structure shown in Fig. 2, the input impedance (Z_{in}) at the air–material interface is given by $Z_{in} = Z_o(\mu^*/\varepsilon^*)^{1/2}\tanh(\gamma d)$, where $Z_o = (\mu_o/\varepsilon_o)^{1/2} \approx 377\ \Omega$ is the characteristic impedance of free space, μ^* and ε^* are the complex relative permeability and permittivity, μ_o and ε_o are the permeability and permittivity of free space, respectively, and $\gamma = j(\omega/c)(\mu^*\varepsilon^*)^{1/2}$ is the propagation factor in the material. By assuming that the thickness of the absorber d is small enough compared with the wavelength λ of the incident TEM wave, the input impedance Z_{in} can be calculated with the equation:

$$Z_{in} = jZ_o\mu^*\omega d/c \qquad (1)$$

The reflection coefficient Γ^* and return loss (or power reflectivity) RL (in decibel, dB) are given by:

$$\Gamma^* = (Z_{in}-Z_o)/(Z_{in}+Z_o) \qquad RL = 20\log|\Gamma^*| \qquad (2,3)$$

It can be seen from the above relation for Γ^* that the principle of the metal–backed single–layer absorber is to make use of the reflection reduction by impedance matching, in which the normalized input impedance with respect to the impedance of free space (Z_{in}/Z_o) should be 1 for no reflection. Therefore, the matching condition for the perpendicular incidence of the TEM wave is given as:

$$(\mu^*\varepsilon^*)^{1/2}\tanh[j2\pi d(\mu^*/\varepsilon^*)^{1/2}/\lambda] = 1 \qquad (4)$$

where λ is the free space wavelength. If λ and/or d are so small that $|2\pi d(\mu^*/\varepsilon^*)^{1/2}/\lambda| << 1$, we are allowed to approximate Eq.(4) to:

$$j2\pi d\mu^*/\lambda = 1 \qquad (5)$$

Introducing the expression $\mu^*=\mu'-j\mu''$ and rearranging Eq.(5), we obtain the following relationships:

$$\mu' = 0 \qquad \text{and} \qquad \mu'' = \lambda/2\pi d \qquad (6,7)$$

The equations involved in formulas (6,7) indicate that we are able to realize a matched absorber with a frequency or wavelength such that it will yield μ' sufficiently less than μ'', provided the thickness d is given by:

$$d = d_m = \lambda/2\pi\mu'' = c/2\pi f_m\mu''(f_m) \qquad (8)$$

where relationship $f_m\lambda = c$ (with c the velocity of light) is taken into account and $\mu''(f_m)$ indicates the value of μ'' at f of f_m. The product of $f_m\mu''(f_m)$ is equivalent to the Snoek's limit $S = (\mu'-1)f_{res}$ [3, 4] with μ' the real part of complex (relative) permeability at $f = 0$ and f_{res} the natural resonance frequency (at which the μ'' has its minimum value). Thus, the Eq.(8) can be modified as follows:

$$d_m \approx c/2\pi S \qquad (9)$$

We used the Eqs.(1–3,8,9) to make a computer program in MATHCAD environment for the design of single–layer absorbers based on prepared composites.

4 RESULTS AND DISCUSSION

Figure 3 shows the complex–plane permeability spectrum $\mu^* = \mu' - j\mu''$ for the sintered $Ni_{0.276}Zn_{0.644}Cu_{0.08}Fe_2O_4$ ferrite. The real part μ', which is about 1418 at low frequencies, starts to decrease at about 1 MHz. The imaginary part μ'' has a maximum of about 573 at around 2.5 MHz. As the frequency rises, the μ' remains level at first and then rises to a shallow peak before falling rapidly to relatively low values. The loss component, μ'', rises to a pronounced peak as μ' falls. This dispersion of permeability is principally due to the natural ferromagnetic resonance (magnetic moment precession resonance). Because there is a distribution of domain magnetizations in unsaturated sintered ferrite, the precession resonance is rather broad. In this case also the domain wall motion contributes to the magnetization process, so wall resonance (or relaxation) contributes to permeability spectrum in this frequency region.

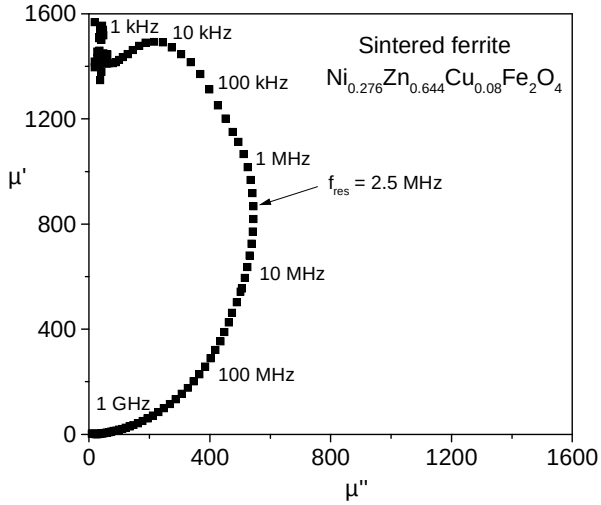

Fig. 3. Complex–plane permeability spectrum of $Ni_{0.276}Zn_{0.644}Cu_{0.08}Fe_2O_4$ sintered ferrite.

Figures 4 and 5 illustrate the complex–plane permeability spectra for NiZnCu ferrite – PVC polymer composites. We can observe a relaxation type of frequency dispersion, which is probably due to the resonance of vibrating domain walls and the natural ferromagnetic resonance of precessing magnetic moments in domains. The values of μ' raise with the filler content but not very much with the filler particle size. Accordingly, the μ^* of composites seems to be affected more by the filler content than by the filler particle size. The resonance frequency f_{res} (at which μ'' has its maximum) of magnetopolymers shifts toward higher frequencies with decreasing of filler concentration. This is attributed to the demagnetizing field H_D formatted by magnetic poles in the surfaces of filler particles in the composite, which leads to increase of resonance frequency according to the equation: $f_{res} = \mu_o\gamma(H_A + H_D)/2\pi$, with $\mu_o = 4\pi\cdot10^{-7}$ H/m the permeability of free space, γ the gyromagnetic ratio, and H_A the magnetocrystalline anisotropy field. This is favourable for microwave surface impedance match in the single–layer EM–wave absorber design because the wavelength in quasi–microwave absorber decreases as the frequency increases.

Figures 6 and 7 present the calculated EM–wave absorbing properties (return loss *RL* in dB as a function of frequency) for two sets of composites (Fig. 6 for a fixed filler particle size and Fig. 7 for fixed filler content) by using the measured complex permeability spectra of magnetopolymers.

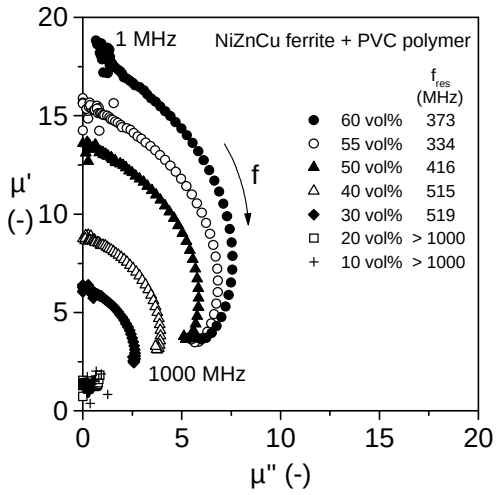

Fig. 4. Complex–plane permeability spectra for magnetopolymers at a fixed filler particle size <*D*> = 0–250 μm.

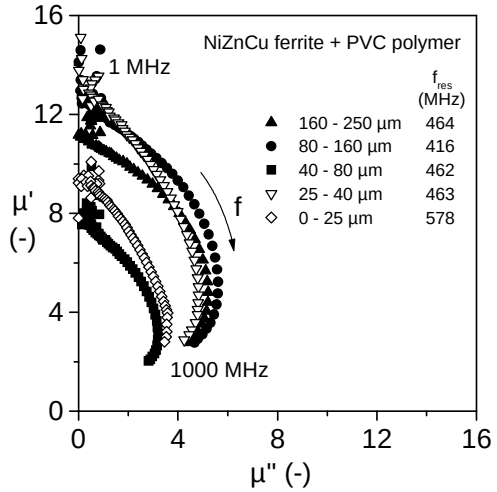

Fig. 5. Complex–plane permeability spectra for magnetopolymers at a fixed filler volume content κ_v = 60 vol%.

The return loss of magnetopolymers is found to depend sensitively on both the filler concentration and filler particle size: the minimum of return loss shifts to high frequency when the filler concentration as well as filler particle size decreases. Also the matching frequency f_m (at which *RL* has its minimum), the matching thickness d_m and the bandwidth (Δf) for $RL \leq -15$ dB were influenced by changes in both the ferrite volume content and ferrite particle size.

The reason for d_m (and also f_m) variation in composites according to filler size and fraction can be found in the basic principles for designing absorbers. The following relationship between d_m and $\mu^* = \mu' - j\mu''$ can be written [2]:

$$d_m \approx (\mu')^{-1/2}[4 \cdot f_m \cdot (1 + tg^2(\mu''/\mu'))]^{-1} \qquad (10)$$

This equation states that d_m is affected (mainly) by μ' and f_m. From figs. 4–7 it follows that increasing filler particle size and fraction causes the increase of μ', which results in the decrease of $f_m \cdot d_m$ value.

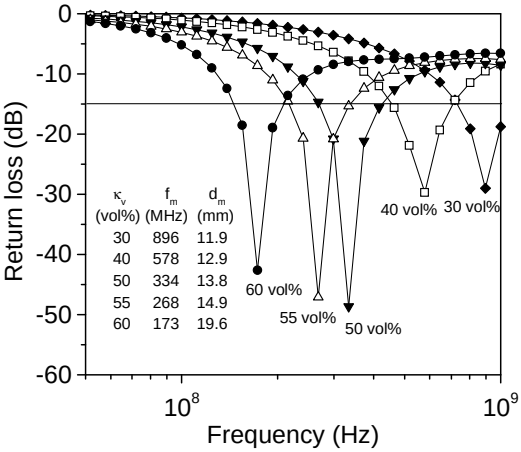

Fig. 6. Return loss as a function of frequency and filler content at a fixed filler particle size <*D*> = 0–250 μm.

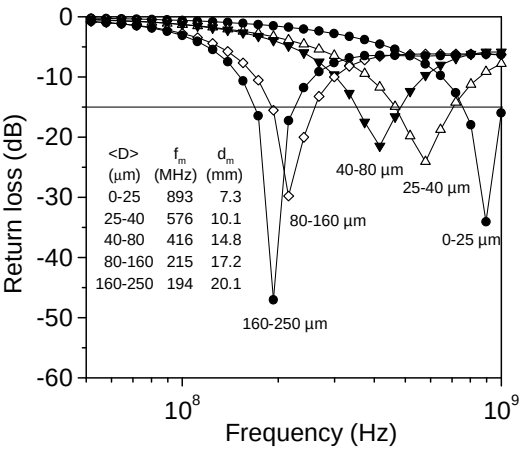

Fig. 7. Return loss as a function of frequency and filler particle size at a fixed filler concentration κ_v = 60 vol%.

Also, f_m decreases with increasing filler particle size and fraction. Although the increase of μ' has effect of reducing absorber thickness *d*, the variation of f_m has larger effect on absorber thickness in the present study. That is because the degree of decreasing in f_m is much larger than that of increasing μ'. On the other hand, because the decrease of μ' is due to arising of demagnetizing fields of ferrite particles in composites, the variation of f_m and d_m is due to the variation of f_{res} according to ferrite particle size and fraction.

5 CONCLUSIONS

The frequency dispersion of complex permeability for NiZnCu ferrite – PVC polymer composite materials has been studied using coaxial transmission line measurement method in the frequency range 1 kHz – 1 GHz. The resonance type of permeability dispersion was observed in the sintered ferrite filler compared to a relaxation type one obtained in composites. The observed frequency dispersions in both the sintered ferrite and composites were originated by the resonance of vibrating domain walls and rotating magnetization vectors in domains. The real part of complex permeability at low frequencies decreased and the resonance/relaxation frequency shifted towards the higher frequency region with the decrease of ferrite particle size and fraction by introducing the demagnetizing field in composites. We have also investigated EM–wave absorbing properties on prepared composites using derived formulas. The most significant result of this study is to provide an effective technique to determine the quasi–microwave absorbing properties from the intrinsic material parameters including the real and imaginary components of complex permeability. The prepared composites can be used for attenuating electromagnetic interference (EMI) in computers and related products (portable and wireless communication electronics, i.e. mobile phones and communicators), switching power supplies, electronic automotive ignition systems, garage doors openers, etc. The EMI suppressor (i.e. composite), suitable also for reducing or eliminating conducted EMI on printed circuit boards (PCB) in wiring and cables, introduces into the circuit a frequency variable impedance and does not affect the lower operating signals but blocks the conduction of the EMI noise frequencies.

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REFERENCES

[1] LIU, J.R. – ITOH, M. – JIANG, J. – MACHIDA, K.: RF Electromagnetic Wave Absorption Properties of ε–Fe_3N/Y_2O_3 Nanocomposites Derived from Y_2Fe_{17} Intermetallic Compound, J. of Magn. Magn. Mat. 277 (2004), pp. 251-256.

[2] KIM, S.S. – JO, S.B. – GUEON, K.I. – CHOI, K.K. – KIM, J.M. – CHURN, K.S.: Complex Permeability and Permittivity and Microwave Absorption of Ferrite–Rubber Composite in X–Band Frequencies, IEEE Trans. Magn. 27 No. 6 (1991), pp. 5462-5464.

[3] DOSOUDIL, R. – UŠÁKOVÁ, M. – FRANEK, J. – SLÁMA, J. – OLAH, V.: RF Electromagnetic Wave Absorbing Properties of Ferrite Polymer Composite Materials, J. of Magn. Magn. Mat. 304 (2006), pp. e755-e757.

[4] DOSOUDIL, R. – FRANEK, J. – UŠÁKOVÁ, M.: Frequency Variation of Complex Permeability of NiZn Ferrite – PVC Polymer Composites and their RF Absorption Properties, Proceedings of AMTEE ´05, Plzeň, Czech Republic, (2005), pp. D19-D24.

[5] SLÁMA, J. – DOSOUDIL, R. – VICEN, R – GRUSKOVÁ, A. – OLAH, V. – HUDEC, I.: Frequency Dispersion of Permeability in Ferrite Polymer Composites, J. Magn. Magn. Mat. 254–255 (2003), pp. 195-197.

[6] SLÁMA, J. – GRUSKOVÁ, A. – VICEN, R. – VICENOVÁ, S. – DOSOUDIL, R. – FRANEK, J.: Composite Material with Substituted Li Ferrite for High–Frequency Applications, J. Magn. Magn. Mater. 254–255 (2003), pp. 642–645.

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