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FTD-ID(RS)T-0292-91

FOREIGN TECHNOLOGY DIVISION

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HUMAN TRANSLATION

FTD-ID(RS)T-0292-91 18 July 1991

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English pages: 12

Source: Beijing Daxue Xuebao, Vol. 26, Nr. 3,
1990, pp. 327-332

Country of origin: China
Translated by: SCITRAN
F33657-84-D-0165
Requester: FTD/SDL/Christopher G. Thomas, 1Lt

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Complex Permeability in Absorption Materials of Spinel Ferrite

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Abstract

To seek high efficiency and wide frequency band of microwave absorber, the requirement of absorber on absorption materials is studied. It is shown that a larger value of permeability (including real and imaginary parts) of absorption material should be obtained so as to design a high quality absorber.

A series of Ni ferrites has been studied. First, the effect of Co addition on complex permeability is studied. Second, the effect of fabrication processes of materials on complex permeability is studied. The experiment results show that the larger complex permeability can be obtained by choosing the Co content and sintering temperature.

Key words: microwave absorber; Ni ferrite; permeability

(This paper was received on November 27, 1989.)

I. Introduction

Microwave absorption materials are widely used in the stealth technology of aircraft, TV image interference of high-rise buildings, and microwave dark room and microwave protection and has attracted much attention. Wide-range study has been carried out to develop microwave absorption materials with high efficiency and, also, new absorption materials are being developed.

Microwave absorption materials can be classified as mono-layer or multiple-layer absorption materials. The absorption requirement for mono-layer materials was discussed in reference [1]. The requirement for multiple-layer absorption materials will be discussed in this paper.

Since the complex permeability of ferrite materials is resonant and varies with frequency (the variation about the resonant region is particularly significant), the range of working frequency of mono-layer absorption materials is usually limited and widening of working frequency is necessary. Calculation showed that if the values of the real and imaginary parts of the complex permeability can be made larger, a wider frequency band could be obtained. For this purpose, this paper will discuss the possibility and method of obtaining high complex permeability based on the magnetization mechanisms.

II. Wave-Absorbing Requirement of Multiple-Layer Absorption Materials

From literature [1], if it is desired to make the quantity of reflection coefficient of mono-layer materials to be as small as possible, the complex permeability and complex permittivity of the absorption materials should have adequate values. What will be the requirement for multiple-layer absorption materials?

As shown in figure 1, for an infinite metallic plate (assuming conductivity $\sigma=\infty$) platted with multiple layers (N layers) of electromagnetic media (the relative complex permittivity, relative complex permeability, transmission coefficient, characteristic impedance were $\varepsilon_r(K)$, $\mu_r(K)$, $\gamma(K)$, $Z_c{}^m(K)$, (K=1,...N) to form a multiple-layer absorption material, then the input impedance on the face of the K-th layer $Z_{in}(k)$ is: [2,3]

$$Z_{in}(k)=Z_c^m(k)\,\frac{Z_{in}(k-1)+Z_c^m(k)\tanh[\gamma(k)d(k)]}{Z_c^m(k)+Z_{in}(k-1)\tanh[\gamma(k)d(k)]} \tag{1}$$

where

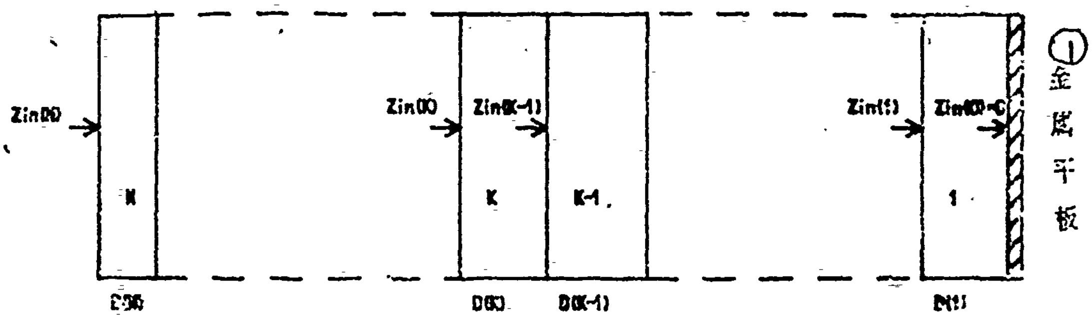
$$Z_c^m(k)=\sqrt{\frac{\mu_0}{\varepsilon_0}}\sqrt{\frac{\mu_r(k)}{\varepsilon_r(k)}} \tag{2}$$

$$\gamma(k)=(j2\pi f/c)\sqrt{\varepsilon_r(k)\mu_r(k)} \tag{3}$$

From above, if the complex permittivity, complex permeability, thickness, and electromagnetic wave working frequency were known, then $Z_{in}(N)$ can be calculation based on equations (1) to (3) with iteration method. This is the input impedance of multiple-layer absorption material.

From the $Z_{in}(N)$ calculated above, the reflection coefficient T and reflection rate R of the multiple-layer material can be calculated from the following equations:

$$\Gamma(N)=\frac{Z_{in}(N)-Z_c^0}{Z_{in}(N)+Z_c^0} \tag{4}$$



key: 1 - metallic plate

Fig 1: Illustration of multiple-layer absorption material

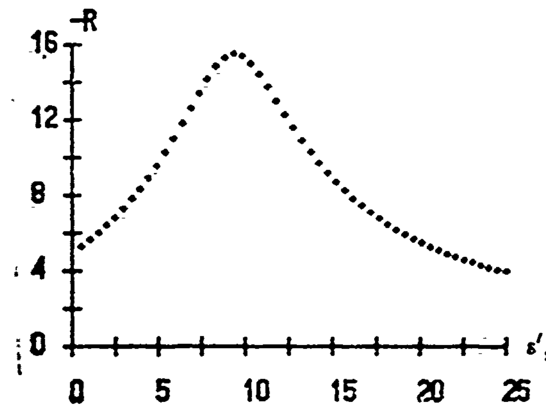
$$R(N)=20\log|\Gamma(N)| \qquad (5)$$

For simplicity reasons, only two-layer absorption material is considered here. Figures 2, 3, 4, and 5 show the relationship between the reflection rate and the real and imaginary parts of the complex permittivity of the second layer and the real and imaginary parts of the complex permeability. (The microwave frequency was assumed to be 9300MHz, the thickness of the first and second absorption materials were 0.68mm and 1.25mm, respectively, and the EM parameters of the first layer were: $\varepsilon_r'(1)=8.08$, $\varepsilon_r''(1)=1.75$, $\mu_r'(1)=1.02$, $\mu_r''(1)=1.56$). /2

From these figures, in order to make the reflection rate of a multiple-layer absorption material as small as possible, adequate values of the complex permittivity and complex permeability is required. In other words, under the condition of fixed microwave frequency and absorption body thickness, to minimize reflection rate, adequate correspondence among the electromagnetic parameters ε_r', ε_r'', μ_r' μ_r'' is required.

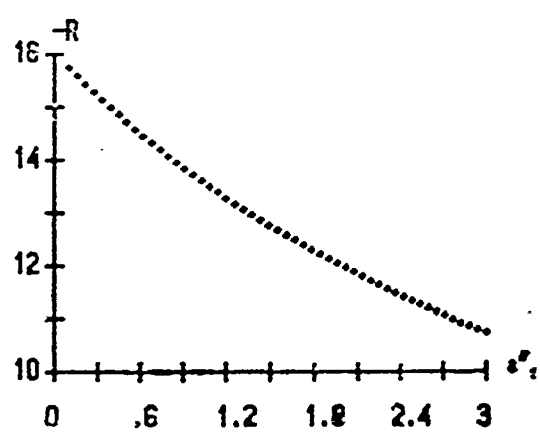
III. Complex Permeability

It is well known that for polycrystalline ferrite materials with cubic lattice structure, the complex permeability induced by free spin magnetic moment in non-isotropic equivalent field and microwave magnetic field can be expressed by the following equation: [4]



$\varepsilon'_r(2) = 0.37$, $\mu'_r(2) = 1.59$, $\mu''_r(2) = 0.52$

Fig. 2: Dependence of reflection coefficient on the real part of complex permittivity



$\varepsilon'_r(2) = 8.54$, $\mu'_r(2) = 1.59$, $\mu'_r(2) = 0.52$

Fig. 3: Dependence of reflection coefficient on the imaginary part of complex permittivity

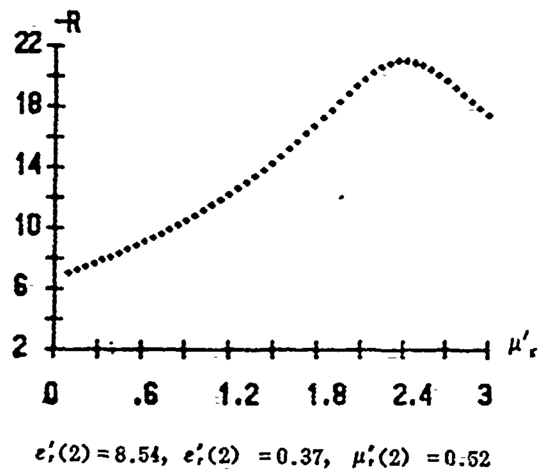


Fig. 4: Dependence of reflection coefficient on the real part of complex permeability

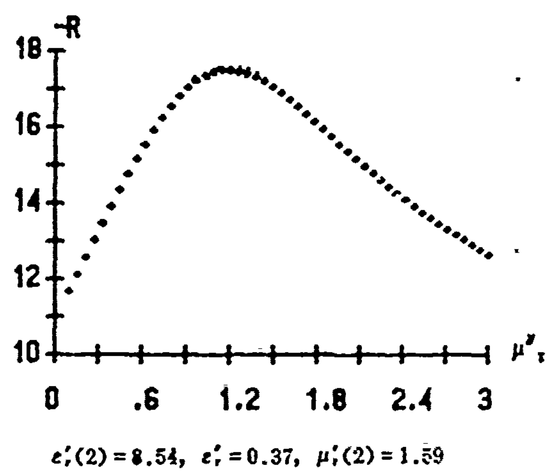


Fig 5: Dependence of reflection coefficient on the imaginary part of complex permeability

$$\mu_r = 1 + \frac{2\omega_m(\omega_a + i\alpha\omega)}{3(\omega_a + i\alpha\omega)^2 - \omega^2} \quad (6)$$

where $\omega_m = \gamma 4\pi M_s$, $\omega_a = \gamma H_a$, $\alpha\omega = \gamma \Delta H/2$, $4\pi M_s$ is the saturated magnetization strength, H_a is the non-isotropic equivalent field ($H_a = -4K1/(3M_s)$, when K1<0,; $Ha = 2K1/M_s$, when K1>0), ΔH is the ferrite resonance band width, and ω is the circular microwave frequency.

From the above equation, the relationship between complex permeability and saturation magnetization intensity, magnetic crystalline non-isotropic equivalent field, and ferrite magnetic resonance band width can be obtained as shown in figures 6, 7, and 8. (The assumption was made that F=9300.0MHz, $4\pi M_s$=3000.0Gs, ΔH=1000 Oe, $K1 = 6.5 \times 10^5 erg/cm^3$.)

From figures 6, 7. and 8, if the natural resonance angular frequency ω_r (for ferrite body with cubic lattice structure the natural angular frequency $\omega_r = \gamma H_a$) is located in the region higher than the microwave working angular frequency ω, complex permeability (including the real and imaginary parts) will have larger quantities. An indication of this analysis is that the material with larger complex permeability is the material of this kind and the natural resonance angular frequency ω_r should be located in the region slightly higher than the microwave working angular frequency ω. For this purpose, the materials with adequate saturation magnetization intensity, magnetic lattice non-isotropic equivalent field, and ferrite resonance band width should be fabricated. As to the technology of controlling ferrite content and manufacturing technique to obtain materials with /3

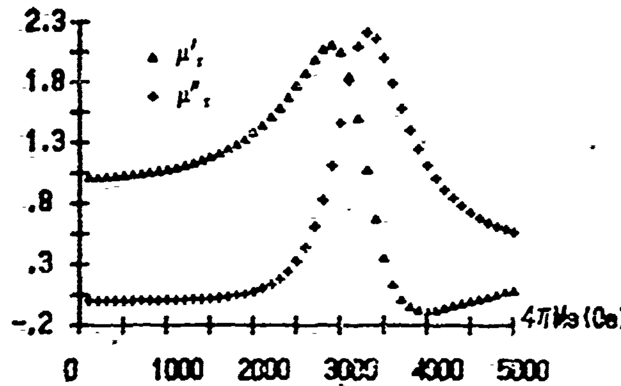


Fig. 6: Dependence of complex permeability on saturated magnetic intensity

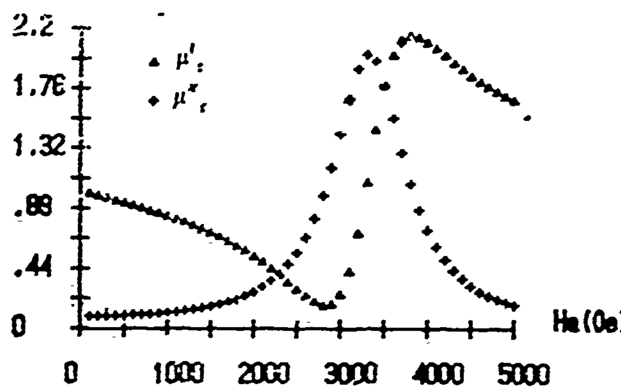


Fig. 7: Dependence of complex permeability on the non-isotropic equivalent field

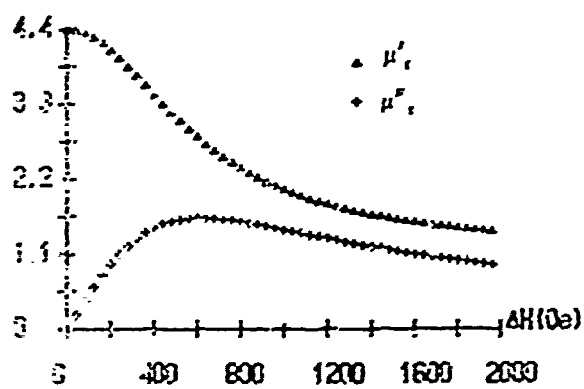


Fig. 8: Dependence of complex permeability on the ferrite resonance band width

adequate saturation magnetization intensity, magnetic lattice non-isotropic equivalent field, and ferrite resonance band width, please referred to literature [1]. /4

IV. Experimental Results and Discussion

Figure 9 shows the dependence of complex permeability (test frequency 9300MHz) of Ni system ferrite $Ni_{1-x}Co_xFe_{20}O_4$ (sintering temperature 1235°C and warming time 4 hours) on the Co content. From this figure, when Co content is in the range of 0.13 to 0.15, the real and imaginary parts of the complex permeability can both have larger values.

Table 1 shows the dependence of complex permeability (including complex permittivity) of spinel ferrite $Ni_{0.87}Co_{0.13}Fe_{20}O_4$ on the sintering temperature at test frequency of 9300MHz. From this table, it is clear that adequate choice of sintering temperature is also important in order to ensure a higher value of the imaginary part of the complex permeability.

V. Conclusions

(1) To minimize the reflection coefficient of a multiple-layer absorption material, the electromagnetic parameters and thickness of the absorption material should be chosen carefully.

(2) The most effective strategy to obtain larger real and imaginary parts of the complex permeability is to change and saturation magnetization intensity, non-isotropic constant, and ferrite magnetic resonance band width of the material so that the

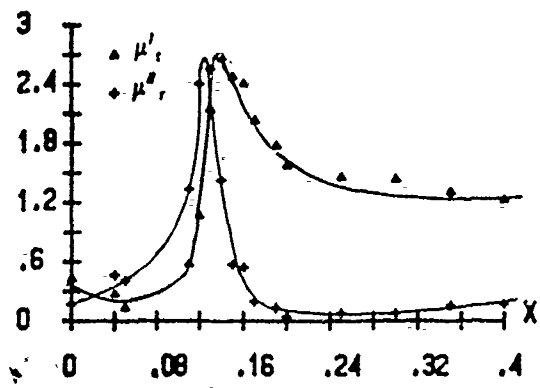


Fig. 9: Dependence of μ_r: on Co content

Table 1. Relationship between μ_r and sintering temperature.

T (°C)	μ'_r	μ'_r	ε'_r	ε'_r
1235	1.8	1.9	11.3	0.20
1260	2.0	3.0	12.2	0.45
1300	1.3	2.8	13.1	14.1

natural resonance frequency is located in the region slightly higher than the microwave working frequency.

(3) Adequate choice of the sintering temperature is important to ensure a larger imaginary part of the complex permeability.

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