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M. Koledintseva et al., "Microwave Filtering of Unwanted Oscillations on Base of Hexagonal Ferrite Composite Thick Films," *Proceedings of the IEEE International Symposium on Electromagnetic Compatibility, 1998*, Institute of Electrical and Electronics Engineers (IEEE), Jan 1998.
The definitive version is available at https://doi.org/10.1109/ISEMC.1998.750159

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MICROWAVE FILTERING OF UNWANTED OSCILLATIONS ON BASE OF HEXAGONAL FERRITE COMPOSITE THICK FILMS

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Abstract: The paper is aimed at the design of waveguide filters of lower frequencies using composite thick films (CTF) made of high-anisotropy polycrystalline hexagonal ferrite powders. Theoretical and experimental results describing the possibility of forming the desired frequency characteristic of the filters are presented.

INTRODUCTION

Elaboration of microwave frequency-selective absorbers of unwanted and harmful radiation is an actual problem, because microwaves are being widely used nowadays in data transmission systems, radar technique, technological installations and other applications. Filtering of unwanted oscillations is necessary for EMC and electromagnetic ecology of microwave active devices application [1]. For these purposes various absorbing materials and coatings (of interference and resistive types) are being elaborated. Most of them absorb electromagnetic radiation only in a narrow frequency band and only at a few certain modes. The widely-spread way of the spurious radiation suppression in the microwave transmitting systems is the application of filters. Choosing of the filter type is determined by the demands to its frequency characteristic, matching of the filter with the main path, value of the induced attenuation on the frequencies of spurious oscillations and on the main harmonic, electrical strength of the filter.

Most of the applied nowadays filters are of the reflecting type, and they as a rule don't satisfy the stringent demands to the mass and size parameters; their constructions are very complicated for technological reproduction, and including the filter into the path leads to the essential decrease of the electrical strength of the path. That's why it is urgent to develop filters of harmonics which get rid of the mentioned above shortcomings. Filter with the improved characteristics may be elaborated on base of the hexagonal ferrite composite material (HFCM), in which the phenomenon of natural ferromagnetic resonance (NFMR) takes place [2].

The construction of the filter contains the waveguide section with inner walls covered with the HFCM having frequency-selective magnetic losses. The HFCM employed in the filter is the mixture of hexagonal polycrystalline ferrite powders distributed in dielectric binder. Application of the HFCM allows to form the desired frequency characteristic of the filter.

PROPERTIES OF HEXAGONAL FERRITE COMPOSITE MATERIALS AND THICK FILMS ON THEIR BASE

There is efficient absorption of the microwave energy in the vicinity of the NFMR at the interaction of hexagonal ferrite particles with microwaves. In the frequency regions far from the NFMR interaction is practically absent. If the HFCM is formed in such a way that its NFMR coincides with the frequencies of the spurious radiation of the microwave source, it is possible to produce microwave transmission line with large losses at these frequencies and low losses in the main operating range.

The NFMR curve form as well as central resonance frequency depend on the chemical structure of hexagonal ferrites. Introduction of different doping ions into the main hexagonal ferrite allows to shift the central NFMR frequency to the side of its increase or, vice versa, decrease. The produced nowadays hexagonal ferrites have the NFMR at frequencies from 1 to 120 GHz [2]. Using a mixture of different hexagonal ferrite powders, it is possible to get composite materials with the desirable amplitude-frequency characteristics.

The frequency characteristics of CTF on base of the HFCM have been studied. Single-layered CTF is the layer of HFCM from 0.2 to 2 mm thick. As required by application of the films, they can be placed on either metal or dielectric substrate.

Due to a number of physical peculiarities of hexagonal ferrites (absence of conductivity losses at resonance absorption of microwave energy; high crystallographic anisotropy magnetic field; dependence of the crystallographic anisotropy field and the NFMR line width on the chemical formula of the powder), the films on their base have a number of advantages. They resist high power levels (P_{aver} ~1 kW); don't need high fields of magnetization; allow to get the needed frequency

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characteristic by means of varying the chemical structure of powders, position and profile of the CTF and have good matching with the waveguide transmission line.

The advantage of HFCM is simplicity of their production. It is possible to produce the filtering of unwanted oscillations, putting the CTF on the waveguide inner walls of the existing microwave device without variation of its basic construction.

MATHEMATICAL MODEL OF HFCM

HFCM on base of hexagonal ferrites is a complicated medium having the following peculiarities:

- bicomplex character (i.e. permeability and permittivity are both complex values);
- permeability is tensor;
- tremendous magnetic losses at the desired for application frequencies;
- grains have inner magnetic moments;
- it is inhomogeneous material.

The research of complex permittivity and permeability of such materials is very urgent. Our studies have shown that it is impossible to use wide-spread waveguide techniques for measuring permittivity and permeability of HFCM without taking into account excitation of higher types of waves in waveguides containing such materials. But the HFCM can be treated as homogeneous by introducing of the effective permittivity and permeability. Choosing the main factors determining the electrodynamic parameters of HFCM, mathematical model of its effective permittivity and permeability calculation and the improved technique of these parameters measurement can be developed.

The analysis of the literature, which deals with the effective medium theories for composite materials with inhomogeneities essentially less than the wavelength of electromagnetic radiation [3-8], shows that the measured values of permittivity of the composite materials with any filling factor of the fractions lie somewhere between the theoretical curves calculated on base of Maxwell-Garnett (MG) model and on base of self-consistent models of Bruggeman type. For low concentration of inclusions in the host material only Lorentz local field interaction of the dipoles can be taken into account, while distances between the particles are so large that they act as independent scatters. That's why the MG model can be used in our case of low filling factor of hexagonal ferrite particles in the dielectric binder.

The MG model for permittivity description can be generalized for the case of tensor permeability of the CGM, as it is done in [9] for Bruggeman formalism.

Let us consider a mixture of isotropic host material (binder) A with constitutive complex parameters ε_A, μ_A and filler B with complex parameters of particles $\varepsilon_B, \vec{\mu}_B$. Volumetric fractions of the materials are f_A and f_B, correspondingly, where $f_B << f_A$. Then, according to MG formalism, we have the following effective parameters of the mixture [3]:

$$\varepsilon_{ef} = \varepsilon_A \frac{1+\frac{2}{3} f_B \alpha_e}{1-\frac{1}{3} f_B \alpha_e}, \qquad (1)$$

$$\alpha_e = \frac{1}{3}\sum_{i=1}^{3} \frac{\varepsilon_B - \varepsilon_A}{\varepsilon_B + L_i(\varepsilon_B - \varepsilon_A)}, \qquad (2)$$

where $\{L_i\}$ is a triplet of depolarization form factors along axes x, y, z for the particles in the form of spheroids.

The analogous formulae for permeability (with taking into account tensor character of $\vec{\mu}_B$) are the following:

$$\vec{\mu}_{ef} = \mu_A(\vec{I} + \frac{2}{3} f_B \vec{\alpha}_m)(\vec{I} - \frac{1}{3} f_B \vec{\alpha}_m)^{-1}, \qquad (3)$$

$$\vec{\alpha}_m = \frac{1}{3}\sum_{i=1}^{3}\left(\vec{\mu}_B - \mu_A \vec{I}\right)\left(\vec{\mu}_B + N_i(\vec{\mu}_B - \mu_A \vec{I})\right)^{-1}, \qquad (4)$$

where $\{N_i\}$ is a triplet of demagnetization form factors along axes x, y, z; $\vec{I}$ is a unit tensor.

Let us analyze the averaged permeability tensor $\vec{\mu}_B$ for the single hexagonal ferrite particle. It is related to the susceptibility tensor:

$$\vec{\mu}_B = \vec{I} + \vec{\chi}_B. \qquad (5)$$

Each component χ_{ij} of tensor $\vec{\chi}_B$ can be represented via distribution functions for crystallographic anisotropy field scatter both in magnitude H_A and in orientation θ_C respectively to the chosen axis of the material texture [10],

$$\chi_{ij} = f_B \int_{\theta_c=0}^{\pi/2} \int_{\Phi_c=0}^{2\pi} \int_{H_{Ak}=0}^{\infty} \chi_{kij}(\theta_k, \Phi_k, H_{Ak}) p(\theta_c, \Phi_c, H_{Ak}) dH_{Ak} d\Phi_c d\theta_c \qquad (6)$$

χ_{kij} is the (ij) component of a corresponding susceptibility tensor for the k-th hexagonal ferrite particle, depending on the polar θ_k and azimuth Φ_k angles between the axis of the k-th particle and the texture axis. The probability density of distribution is determined by the formulae [10]:

$$p(\theta_C, \Phi_C, H_{Ak}) = p(x)p(H_{Ak}) \;, \qquad (7)$$

where $p(x)$ is the distribution density for the texture of material, $x = |\cos\theta_C|$, for the material with any texture parameter ν (at ν=0 the material has no texture) the probability density can be assumed as

$$p(x) = (1+\nu)x^{\nu} \,. \qquad (8)$$

The probability density $p(H_{Ak})$ can be represented in Cauchy form, where H_A is the mean value of anisotropy fields of particles, H_{Ak} is the anisotropy field of the k-th particle, ΔH_A is the half width of the anisotropy fields scatter:

$$p(H_{Ak}) = \frac{1}{\pi} \times \frac{\Delta H_A}{(H_{Ak} - H_A)^2 + \Delta H_A^2}; \qquad (9)$$

This allows to get susceptibility tensor of the hexagonal ferrite in its ordinary 9-component form [11].

The improved method of absorption evaluation is based on the numerical solution of complex dispersion equation for the CTF (having the calculated effective permeability and permittivity) placed into the rectangular waveguide with taking into account higher modes, excited in the rectangular waveguide. This equation can be obtained for the multi-layered structure, for example, by longitudinal LE and LM waves technique [12].

EXPERIMENTAL RESULTS AND DISCUSSION

Investigation of the CTF were carried out on the waveguide section in the frequency range from 8 to 37,5 GHz. Laboratory samples of CTF were produced of powders of barium hexagonal ferrite doped by scandium ions, which efficiently absorbs microwaves at frequencies f > 15 GHz and has low absorption in the frequency range 8-12 GHz. As a binder we used paraffin, epoxy resin, PVA glue.

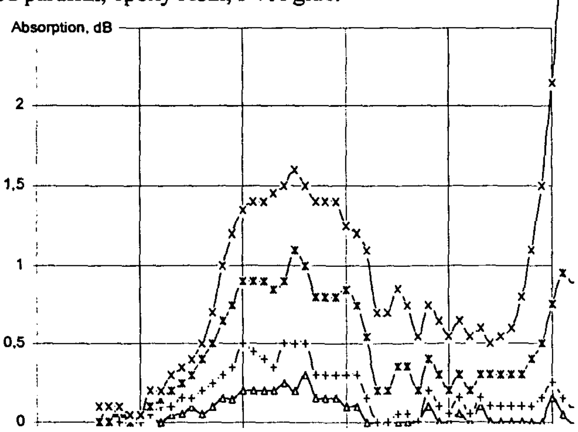

Figure.1 .Frequency dependence of absorption at placing CTF with PVA on the narrow wall of rectangular waveguide

Fig.1 and 2 demonstrate the frequency dependence of microwave absorption in the waveguide at placing CTF with PVA glue on the narrow wall and wide wall, correspondingly.

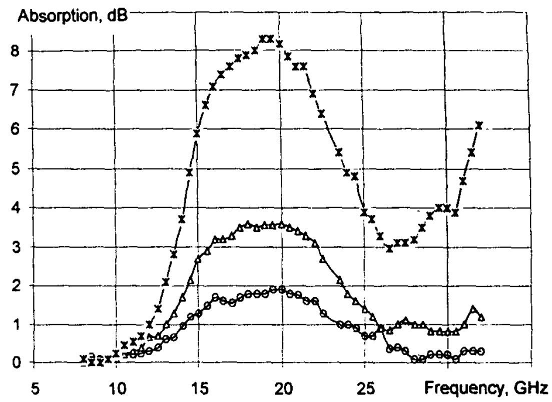

Figure.2 .The dependence of the microwave absorption on the frequency at placing CTF with PVA on the wide wall of rectangular waveguide

Fig.3 shows frequency dependence of absorption in the same ferrite with epoxy glue binder placed on the wide wall of the waveguide. Using the mixtures of doped barium hexagonal ferrites with various NFMR frequencies, it is possible to control the frequency characteristic of the films absorption.

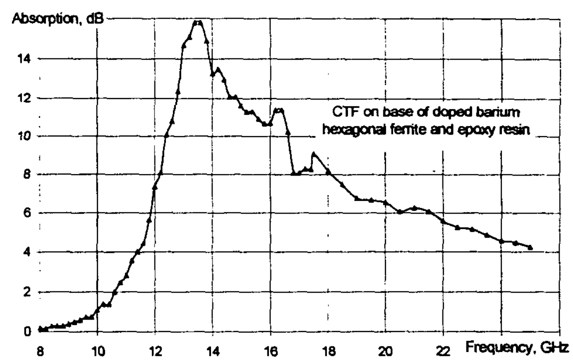

Figure.3. .The dependence of the microwave absorption on the frequency at placing CTF with epoxy resin on the wide wall of rectangular waveguide

Fig.4 shows the frequency dependence of microwave energy absorption in the waveguide with the film made of a mixture of two doped barium hexagonal ferrites with different chemical structure in PVA binder. This film is placed on the wide wall of the waveguide.

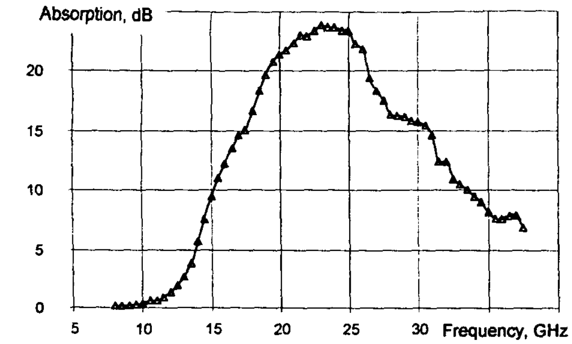

Figure 4. Frequency dependence of absorption in the waveguide with the two-component CTF placed on the wide wall of the waveguide.

For the increase of absorption in the waveguide the multi-layered CTF were studied. Multi-layered CTF consist of HFCM layers and dielectric slabs between them. Like in the case of single-layered films, the absorption in them is conditioned by presence of the doped barium hexagonal ferrites. In the study of multi-layered CTF there were used specially produced samples of multi-layered films, as well as a packet of two single-layered with previously known characteristics.

The influence of the dielectric layer thickness on the absorption in the multi-layered CTF was studied using fluorine plastic slabs of different thickness between the CTF layers. The absorption characteristics at placing CTF on the narrow wall of the waveguide are represented in Fig.5.

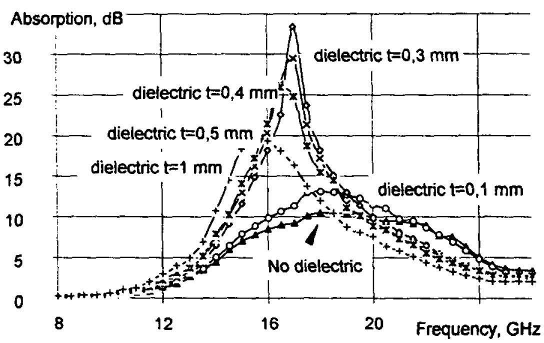

Figure 5. Dependence of absorption on the frequency for CTF with different dielectric slabs.

As it is seen in Fig.5, there is an optimum thickness of the dielectric layer. In this case, maximum absorption of the microwaves is observed at the dielectric slab having thickness 0,3 mm.

The comparison of absorption characteristics for multi-layered films having thickness of 0.3 mm placed on the wide and narrow walls of the waveguide is represented in Fig.6.

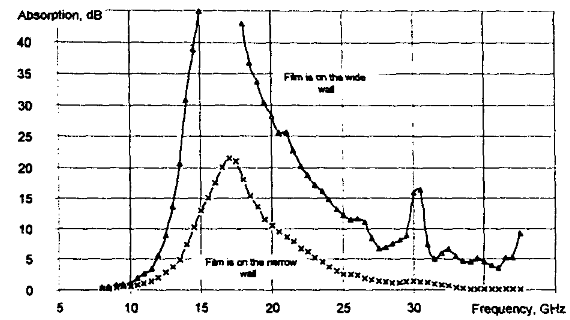

Figure 6. Absorption characteristic of multi-layered CTF with PVA binder and fluoroplastic slab on narrow and wide walls of the waveguide.

Multi-layered CTF placed on the wide wall of the waveguide (see Fig.6) provides suppression of unwanted oscillations about 30-40 dB in frequency range from 14 to 18 GHz. At frequencies 7-8 GHz losses don't exceed 0.2-0.3 dB.

There is increase of absorption in multi-layered film compared to the single-layered ones. There is also an evident shift of the central resonance frequency at varying the dielectric thickness. Absorption in multi-layered films is essentially more than in the single-layered ones.

Fig.7 demonstrates the absorption curves for single-layered and multi-layered films on base of two-component HFCM and epoxy resin binder.

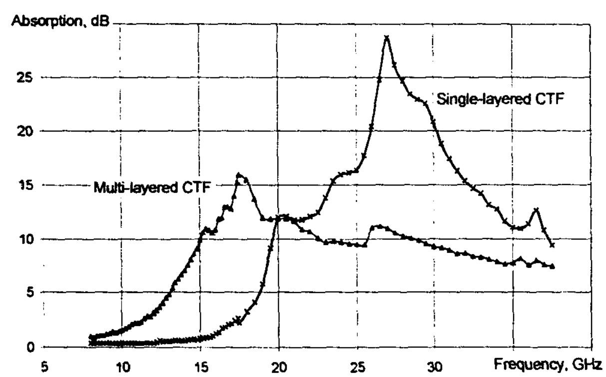

Figure 7. Dependence of absorption on frequency for single- and multi-layered CTF with epoxy resin.

There is an essential shift of resonance frequency in the multi-layered CTF from that for the single-layered CTF due to the presence of fluoroplastic slab. Though peak absorption lessens, the absorption curve width increases when using multi-layered CTF. Thus, it is possible to vary the frequency characteristic of absorption not only by using multi-component ferrites, but also by using dielectric slabs in multi-layered CTF.

PRACTICAL APPLICATION OF CTF

We studied application of our elaborated CTF in filters of spurious radiation for EMC purposes in domestic devices. The filter with frequency characteristic shown in Fig.8 allows to suppress unwanted radiation of higher harmonics produced by microwave oven.

This filter contains single-layered multi-component hexagonal ferrite CTF on base of epoxy resin, placed on the wide wall of rectangular waveguide. The filter was tested at levels of continuous power up to 1 kW.

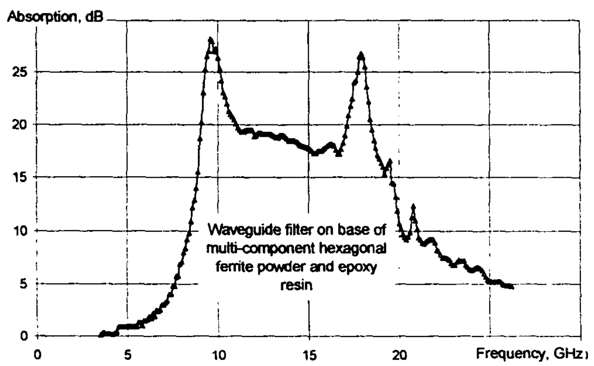

Figure 8. Frequency characteristic of filter of harmonics for suppression of spurious radiation of microwave ovens

CONCLUSION

Application of HFCM and thick films on their base allows to produce filtering devices of absorbing type with the desired form of amplitude-frequency characteristic. Technological simplicity, possibility to work at high power levels, efficient suppression of spurious oscillations in devices on base of the HFCM and CTF allow to use these materials for electromagnetic compatibility of microwave active devices without varying their basic construction.

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