Ferromagnetic resonance in 3D-printing hexagonal ferrite $BaFe_{12}O_{19}$ composite at the EHF frequency range

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***Abstract* — Results of research of electromagnetic response of 3D-printing hexagonal ferrite $BaFe_{12}O_{19}$ composite at frequency range 34-250 GHz at room temperature are presented. Region of natural ferromagnetic resonance near 46.5 GHz was found. The possibility of creating a 3D-printing of frequency selective shielding's based on the developed material is shown.**

I. INTRODUCTION

TODAY, materials with desired electrophysical properties for 3D-printing by fused deposition modeling (FDM) are improved, their scope of application is expanding.

Composite filaments based on inclusions of modified carbon, ferrites, metals and polymers [1-7] are being developed. Of particular interest is the creation of composites for 3D-printers based on acrylonitrile butadiene styrene (ABS) with inclusions of hexagonal M-type ferrite $BaFe_{12}O_{19}$ (ABS/$BaFe_{12}O_{19}$), which has a region of natural ferromagnetic resonance (NFMR) in the EHF range [4]. Thus, this composite filament can be used for the manufacture of frequency-selective absorbing coatings of any geometry by the additive layer-by-layer fusion technology.

This paper describes the process of manufacturing the filament for 3D-printer based ABS/$BaFe_{12}O_{19}$ and the electromagnetic properties of the specimen obtained in the EHF range.

II. RESULTS

For researches planeparallel sample of composite 2.4 mm thick consist of ABS with the 40 wt.% of hexagonal ferrite $BaFe_{12}O_{19}$ with particles less than 80 micrometers was prepared by FDM 3D-printing technology. The initial powder mixture of ferrite for 10 minutes was subjected to mechanical activation and grinding in a high-energy planetary ball mill with a ratio of steel balls 5:1.

Composite production was carried out in several stages. At the first stage, the starting material (ABS) was ground to fine particles (less than 2 mm). Next, demethylketone was used to dissolve the ABS particles to the state of a homogeneous mass. At the next technological stage, $BaFe_{12}O_{19}$ ferrite powder was added. The mixture was left to dry for 24 hours for complete polymerization of the composite. By the method of mechanical grinding, the prepared composite was brought to the state of particles with a diameter of less than 1 mm.

Researches of electromagnetic response of ferrite samples were carried out by using backward-wave oscillator (BWO) quasioptical measurement system (Figure 1). An acousto-optic converter was used as a detector (Golay cell).

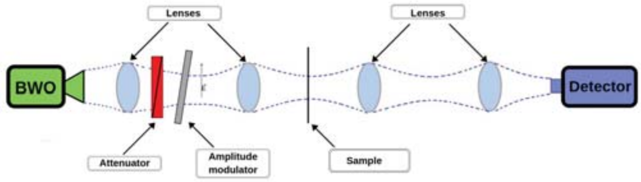

Fig. 1. The experimental setup of quasioptical system for researching of the electromagnetic properties of solid materials at the EHF range

Analysis of the frequency dependence of the transmission (Figure 2) and reflection (Figure 3) coefficients in the range of 34 - 250 GHz showed the presence of the absorption region with a maximum near the frequency 46.5 GHz at temperature 296 K.

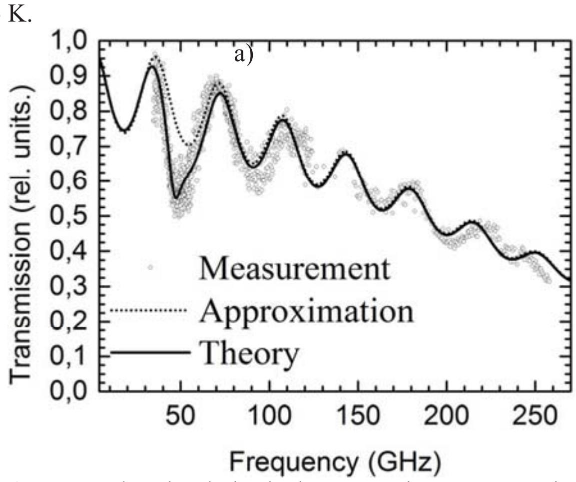

Fig. 2. Measured and calculated electromagnetic wave transmission coefficient of ABS/$BaFe_{12}O_{19}$ composite at room temperature.

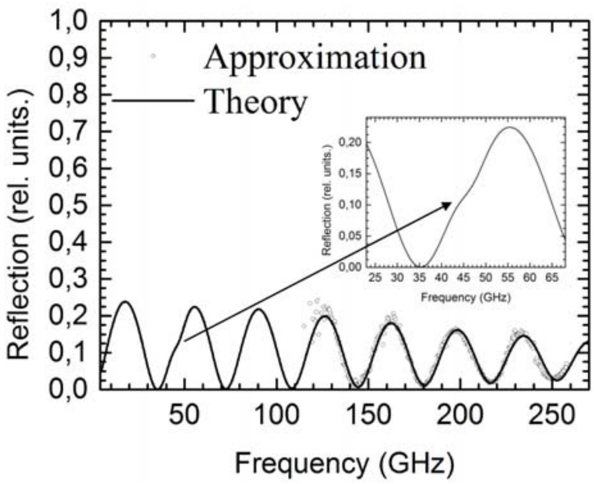

Fig. 3. Measured and calculated electromagnetic wave reflection coefficient of ABS/$BaFe_{12}O_{19}$ composite at room temperature.

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Expression describes theoretical transmission coefficient T as form (1):

$$T = (1-\rho^2)\frac{\exp(-i\gamma d)}{1-\rho^2\exp(-2i\gamma d)} \quad (1)$$

where d is thickness of specimen; γ has form (2):

$$\gamma = \frac{\omega\sqrt{\mu^*\varepsilon^*}}{c} \quad (2)$$

there μ^* complex magnetic permeability; ε^* is complex dielectric permittivity; c is propagation constant of light in vacuum; ω is cyclic frequency; ρ described by:

$$\rho = \frac{z^*-1}{z^*+1} \quad (3)$$

z is complex wave resistance of medium:

$$z^* = \sqrt{\frac{\mu^*}{\varepsilon^*}} \quad (4)$$

Calculations of permeability was assumed to approximate dielectric constant (without resonance). Approximation of transmission index with permeability μ calculated by model of ferromagnetic resonance [8] shows agreement with the measured results.

$$\mu = 1 + \frac{4\pi M_s\left[H_r + i(\omega/\gamma)\alpha\right]}{H_r^2-(1+\alpha^2)(\omega/\gamma)^2+2i\alpha(\omega/\gamma)H_r} \quad (5)$$

In formula (5) M_s = 0.0358kGs is saturation magnetization, H_r=16.7 kOe is the value of the anisotropy field, ω is the angular frequency of the electromagnetic field, γ is gyromagnetic ratio ($\gamma/2\pi$ =2.8 GHz/kOe), α=0.10 is damping constant. Based on the measured dielectric constant outside the NFMR region, an approximation of the frequency dependence of the permeability for calculation was obtained (Figures 4-5).

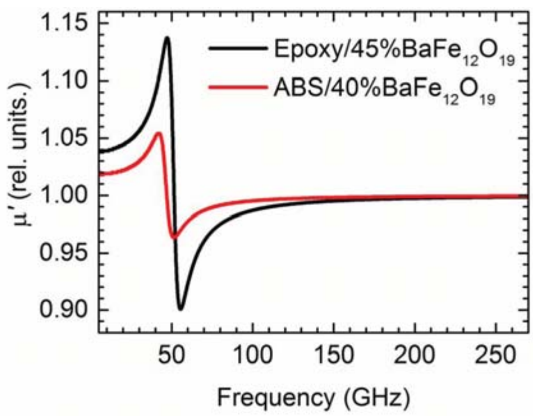

Fig.4. Calculated real part of permeability of ABS/40%$BaFe_{12}O_{19}$ and Epoxy/45%$BaFe_{12}O_{19}$ composites at the frequency range 5-270 GHz at room temperature.

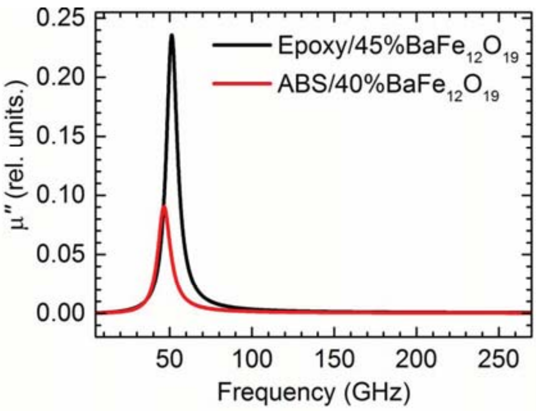

Fig.5. Calculated imaginary part of permeability of ABS/40%$BaFe_{12}O_{19}$ and Epoxy/45%$BaFe_{12}O_{19}$ composites at the frequency range 5-270 GHz at room temperature.

The results of the ABS/$BaFe_{12}O_{19}$ composite for 3D-printing correlate with the data for the $BaFe_{12}O_{19}$ composite based on epoxy [9].

Mass concentration (%)	Matrix	$f_{res.}$ (GHz)	ε'	ε''	H_r (kOe)	M_S (kG)	α
45	Epoxy	52.0	4.46	0.06	18.35	0.082	0.08
40	ABS	46.5	3.00	0.04	16.70	0.036	0.10

Table 1. Parameters of the composite based on epoxy and ABS with $BaFe_{12}O_{19}$ powder. Here $f_{res.}$ is NFMR frequency, ε' and ε'' are real and imaginary parts of permittivity at NFMR frequency, M_s is saturation magnetization, H_r is the value of the resonant field, α is damping constant.

III. Summary

Thus, in this study, we have shown the presence of the frequency region of NFMR in 3D-printed ABS/$BaFe_{12}O_{19}$ composite at about 46.5 GHz. This composite may be of interest to manufacturers of filaments for FDM 3D-printers.

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