Ferromagnetic resonance in hexagonal ferrite $Ba_3Co_2Fe_{24}O_{41}$ at the THz frequency range

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***Abstract* — The research of electromagnetic response of $Ba_3Co_{2.4}Ti_{0.4}Fe_{23.2}O_{41}$ hexaferrite at frequencies 100-975 GHz in temperature range from 296 to 428 K are presented in this paper. At a frequency about ~ 930 GHz the resonance absorption of electromagnetic wave energy was found. We explain this by the presence of magnetic resonance in materials with helical magnetic ordering.**

I. INTRODUCTION

The ferrites with hexagonal crystal structures are the materials with relatively high value of magnetic permeability at microwave frequency range [1]. It is believed that the phenomenon of natural ferrimagnetic resonance (NFMR) in hexaferrites at frequencies higher than 200 GHz is not observed. Antiferromagnetic resonance can be observed at frequency up to infrared range by applying sufficiently large magnetic fields. However, in [2] theoretically and experimentally shown that in chromium spinel $CdCr_2O_4$ with helical magnetic ordering high frequency magnetic resonance modes are observed. Some of these modes are excited in the absence of the magnetizing field and they are inherently similar to the NFMR.

At substitution of the Fe^{3+} ions by complex $Co^{2+}Ti^{4+}$ in $Ba_3Co_2Fe_{24}O_{41}$ (Co_2-Z) hexaferrite the local distortions of symmetry of exchange interactions are arise. This can lead to the appearance of the anisotropic exchange interaction and antisymmetric exchange interaction of Dzyaloshinskii-Moriya In this case there are favorable conditions for the emergence of a helical magnetic ordering [3]. To study the electromagnetic response and electromagnetic parameters at frequency range 100 - 975 GHz the hexaferrite composition $Ba_3Co_{2.4}Ti_{0.4}Fe_{23.2}O_{41}$ (CoTi-Z) was chosen.

II. RESULTS

For researches sample of the hexagonal ferrite in the form of planeparallel polished plate 440 μm thick was prepared.

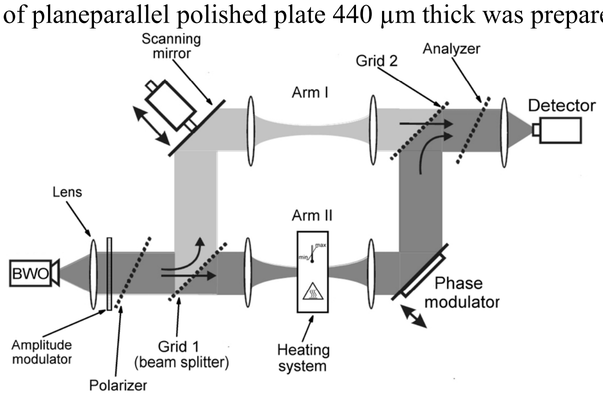

Fig. 1 The experimental setup of the Mach-Zender interferometer for researching of the influence of the temperature on solid materials at THz region.

Researches of electromagnetic response of ferrite samples were carried out by use quasioptical Mach-Zehnder interferometer (Figure 1). Mach-Zehnder interferometer consist of two arms (working and reference). Backward-wave oscillator as a source of monochromatic electromagnetic wave was used. Focusing of quasi-optical beam was carried with teflon lenses. The grid 1 provided beam separation into two with parallel and orthogonal polarizations respectively. Radiation passed through working and reference arms fell through grid on detector. As a detector of terahertz radiation was used optoacoustic converter (Golay cell). In process of change of frequency scanning mirror adjusts to minimum signal on detector and made a record of phase shift. Recording of transmission coefficient was performed at closed reference arm. Investigated sample of ferrite was placed in heating system in working arm, which provides maintenance of set temperature. On figure 2 measured and calculated transmission indexes of CoTi-Z hexaferrite sample in frequency range from 100 to 975 GHz at temperature 296 K are presented.

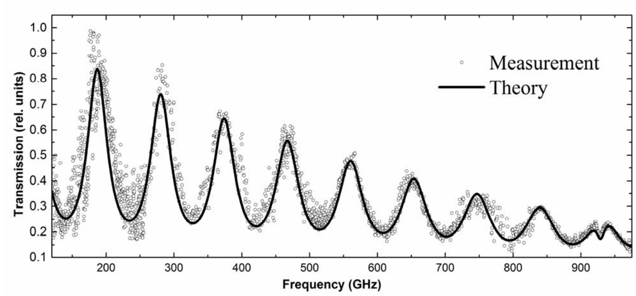

Fig. 2 Measured and calculated transmission indexes of $Ba_3Co_2Fe_{24}O_{41}$ ferrite sample in frequency range from 100 to 975 GHz at temperature 296 K.

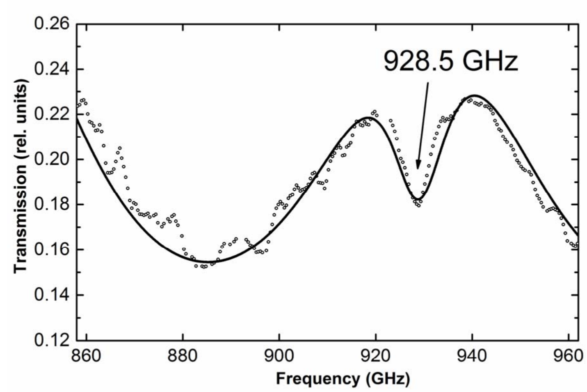

Fig. 3 Measured and calculated transmission indexes of $Ba_3Co_2Fe_{24}O_{41}$ ferrite sample in frequency range from 860 to 961 GHz at temperature 296 K.

Analysis of the frequency dependence of the transmission coefficient in the range of 100 - 975 GHz showed the presence of the absorption region with a maximum at the frequency 928.5 GHz at temperature 296 K (Figure 3).

Expression describes theoretical transmission coefficient T has form:

$$T = (1-\rho^2)\exp(-i\Gamma d)/(1-\rho^2\exp(-2i\Gamma d)), \quad (1)$$

where d is thickness of sample; the EMW propagation constant Γ is

$$\Gamma = (\omega/c)\sqrt{\mu\varepsilon}. \quad (2)$$

There μ is complex permeability; ε is complex permittivity; c is a speed of light in vacuum; ω is the angular frequency of the electromagnetic field; ρ described by:

$$\rho = (Z-1)/(Z+1). \quad (3)$$

Here $Z = \sqrt{\mu/\varepsilon}$ is the wave impedance.

Processing of the spectra of the $|T(f)|$ was carried out as follows:

We do not take into account the presence of the resonance peak near a frequency of 929 GHz at the first stage. Assuming μ = 1 we have estimated by the standard method the values of the real (ε' = 13.4) and imaginary (ε" = 0.4) parts of the permittivity from the measured module and the phase of the transmission coefficient.

To describe the presence of the resonance peak near the frequency f =929 GHz, we used the formula for diagonal components of magnetic permeability tensor from work [4] at the second stage:

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

In formula (4) M_s is saturation magnetization, H_r is the value of the resonant field, γ is gyromagnetic ratio (γ/2π = 2.8 GHz/kOe for the spin moment of the electron) and α is damping constant. These parameters were estimated by fitting the position, width and intensity of the resonance peak at frequency dependencies $|T(f)|$. The values of these parameters for various temperatures of the sample are shown in Table 1.

T, K	$f_{res}=\gamma H_r$, GHz	H_r, kOe	M_S, kGs	α
296	928.5	331.6	0.047	0.0085
333	924.8	330.5	0.046	0.0090
367	918.2	329,9	0,042	0,0094
391	916.5	328.2	0.040	0.0100
428	914.0	327.5	0,037	0.0102

Table 1. Measured temperature dependences of parameters of $Ba_3Co_{2.4}Ti_{0.4}Fe_{23..2}O_{41}$ ferrite.

Calculated according to the data in Table 1 spectra of the real (μ') and imaginary (μ") parts of permeability are shown in Figures 4 and 5.

It's clear that heating the sample in the temperature range from 296 K to 428 K reduces the values of resonance frequency, resonance field H_r and M_S. The parameter α is increased.

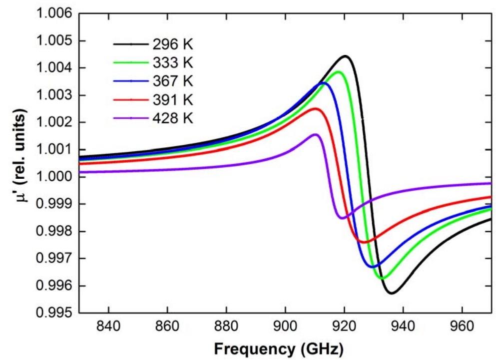

Fig. 4 Real part of magnetic permeability of ferrite in the frequency range 830-970 GHz at temperatures from 296 to 428 K

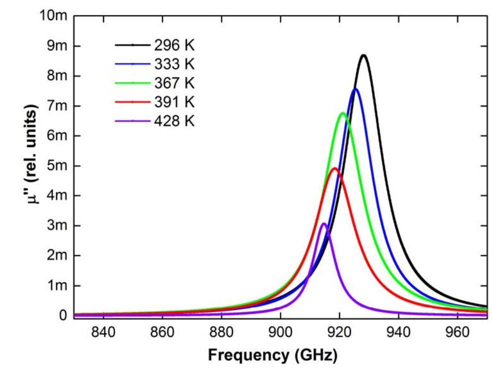

Fig. 5 Imaginary part of magnetic permeability of ferrite in the frequency range 830-970 GHz at temperatures from 296 to 428 K

Such behavior of magnetic parameters with increasing of temperature: reduction the values of resonance field and saturation magnetization and an increase of the damping constant are typical for the parameters of resonance with magnetic nature.

Note that the measured values of the resonant frequencies are closed to the frequency one of the oscillation modes in a material with a helical magnetic ordering.

III. Summary

Thus, in this study we observed and studied the resonance, which is well described by magnetic resonance model. The estimations of the resonance parameters were performed.

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