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Features of the Permeability Spectra of CoZnW Hexaferrites in the Spin-Reorientation Phase Transition Region

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The ferrites with hexagonal crystal structures (hexaferrites) of the $Co_{2-x}Zn_xW$ system have a number of outstanding properties among other hexaferrites. This makes them promising both for obtaining new physical data and for practical use. In this presentation we analyze the concentration and temperature dependences of the resonance frequencies of natural ferromagnetic resonance and the damping constant in the equation of motion of the magnetization vector of these materials in the vicinity of spin-reorientation phase transitions. It is shown that these hexaferrites can find practical application, in particular as radar absorbing materials, in the entire microwave frequency range.

INTRODUCTION

An important characteristic of the hexaferrites is the magnitude and sign of the magnetocrystilline anisotropy (MCA) fields. The values of MCA fields of the Me_2W hexaferrites are within the limits of 10 – 20 kOe for bivalent Fe^{2+}, Ni^{2+}, Mg^{2+} , Zn^{2+} and Cu^{2+} ions and their combinations [1]. These materials possess MCA of the easy magnetization axis (EMA). This axis is the hexagonal axis *c* of the crystal lattice. However, the application of this hexaferrites as a radar absorbing materials is limited by millimeter wavelengths with frequencies of ~ 30 – 60 GHz because of their strong anisotropy fields.

[1]. J. Smit and H.P.J. Wijn, Ferrites, London: Cleaver-Hume Press Ltd., 1959.

INTRODUCTION

The Co_2W hexaferrite has MCA of the easy magnetization plane (EMP) type. The MCA field is more than –20 kOe at room temperature [1]. The minus sign means the EMP-type anisotropy. The spin-reorientation phase transition (SRPT) from EMA to EMP type anisotropy will be observed in solid solutions of the Co^{2+} containing hexaferrites combined with the above-listed ions with increasing cobalt ion content. SRPT are observed not only for concentration but also for temperature changes. The values of the MCA fields can vary in a wide range with changes of the Co^{2+} concentration [2].

[1]. J. Smit and H.P.J. Wijn, Ferrites, London: Cleaver-Hume Press Ltd., 1959.

[2]. V. A. Zhuravlev, “Ferromagnetic resonance in the polycrystalline hexagonal ferrites $Co_{2-x}Zn_xW$,” Physics of the Solid State, vol. 41, pp. 956-959, June 1999.

INTRODUCTION

It offers the possibilities of $Co_{2-x}Me_xW$ hexaferrites application for radar absorbing materials in the entire microwave range starting from ~1 GHz. Most of the articles devoted to the use in the microwave frequency range of the $Co_{2-x}Zn_xW$ hexaferrite do not consider the effect of the concentration and the temperature SRPT on the permeability spectra ($\mu^*(f) = \mu'(f) - i\mu''(f)$). Here $\mu'(f)$ is the real and $\mu''(f)$ is the imaginary parts of the permeability.

The aim of this work is to study the features of some main parameters of the permeability spectra (PS) of the hexaferrites $Co_{2-x}Zn_xW$ system with a change in the concentration of zinc ions and temperature.

SOME THEORETICAL BACKGROUNDS

The dispersion of the permeability spectra (PS) observed in the microwave frequency range is related to the natural ferromagnetic resonance (NFMR). Consequently, the concentration and temperature dependences of the PS of the $Co_{2-x}Zn_xW$ hexaferrites in the vicinity of the SRPT should have features. In further analysis of the permeability spectra, we restrict ourselves to calculations for single-domain noninteracting spherical particles. In the region of existence EMP type anisotropy, the resonance frequency (f_r) of the NFMR is determined by the formula:

$$2\pi f_r = \gamma(|H_\Theta|\, H_\Phi)^{1/2}, \qquad (1)$$

and in the EMA region:

$$2\pi f_r = \gamma H_{a1}. \qquad (2)$$

Here, $H_\Theta = H_{a1} + H_{a2} + H_{a3}$ is the anisotropy field relative to the basal plane, H_{a1} is the anisotropy field along the hexagonal axis and $H_{ai}=2ik_i/M_S$.

$H_\Phi = 36\,\kappa_4/M_S$ is the anisotropy field in the basal plane, k_i are the i-th order anisotropy constants. M_S is the saturation magnetization, γ is the magnetomechanical ratio.

SOME THEORETICAL BACKGROUNDS

The magnitude of the imaginary part of the permeability of the isotropic polycrystalline sample at resonance in both cases can be estimated as

$$\mu''_r = (\gamma 4\pi M_S)/(3*2\pi f_r \alpha), \qquad (3)$$

where α is the dissipation parameter in the equation of motion of the magnetization vector. Formulas (1) - (3) were obtained under the assumption that dissipation is small.

The H_{a1} MCA field changes sign at the SRPT transition EMA ↔ EMP. Therefore a minimum should be observed in the temperature or the concentration dependences of $2\pi f_r$ according to (1), (2).

In addition, an increase in the dissipation parameter can be expected in the SRPT region.

CONCENTRATION DEPENDENCES OF THE PARAMETERS OF THE PERMEABILITY SPECTRA AT ROOM TEMPERATURE

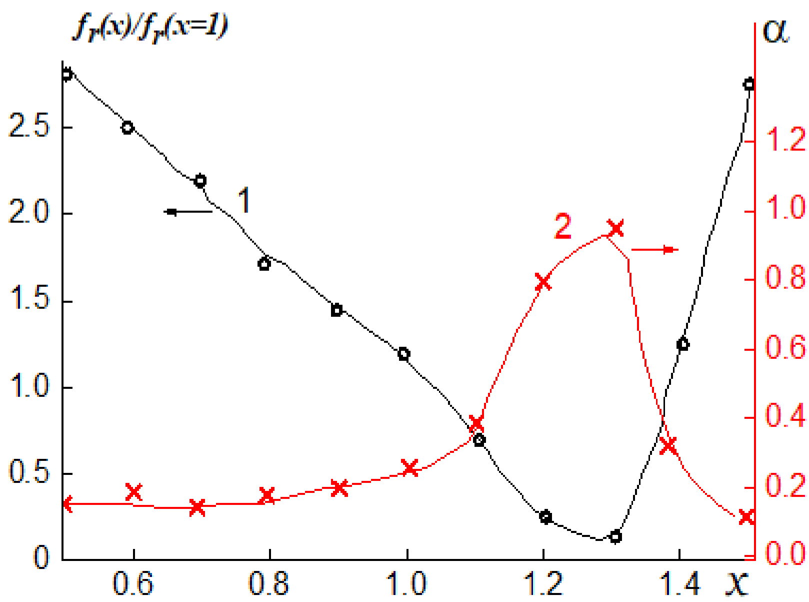

Fig.1. Concentration dependence of $f_r(x)/f_r(x=1.0)$ determined from the maximum of μ"(f_r) (curve 1) and the concentration dependence of the dissipation parameter α(x) (curve2). The measurements were carried out at room temperature.

The concentration dependence of $f_r(x)$ is normalized to the value of $f_r(x=1)$ = 6.1 GHz. In the EMP state the frequency $f_r(x)$ decreases with increasing x, reaches a minimum near the concentration of ions Zn^{2+} $x \approx 1.3$ and then quickly increases. The minimum value of $f_r(x=1.3)$ is 0.6 GHz. The maximum in the concentration dependence of α(x) takes place at $x \approx 1.3$. The easy magnetization cone (EMC) state is observed for ferrite with $x_c = 1.3$. Materials with $x \geq 1.38$ have EMA states. Anomalies observed in the dependences $f_r(x)/f_r(x=1.0)$ and α(x) are related to SRPT. According to Fig. 1, the change in the concentration of zinc ions allows the frequency of NFMR to widely vary.

TEMPERATURE DEPENDENCES OF THE PARAMETERS OF THE PERMEABILITY SPECTRA

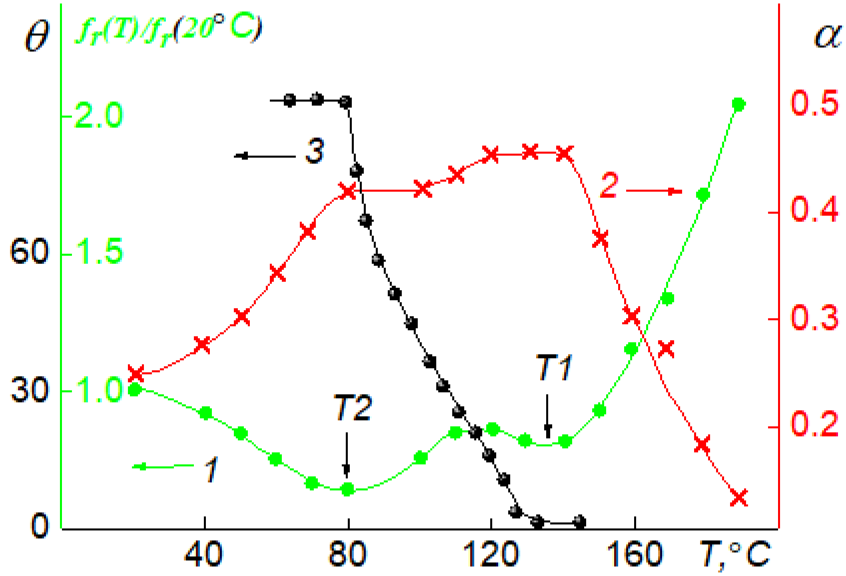

Fig. 2. Temperature dependences of the normalized resonance frequency NFMR $f_r(T)/f_r(20\ °C)$ (curve 1) and $\alpha(T)$ (curve 2) of the hexaferrite Co_1Zn_1W. Curve 3 is the calculated from the neutron diffraction data temperature dependence of the angle of easy magnetization direction $\theta(T)$ of the given hexaferrite.

More detailed information on the behavior of the PS in the region SRPT EMP ↔ EMA can be obtained from the study dependences $f_r(T)$. Fig. 2 shows the dependences $f_r(T)/f_r(T=20°C$ and the damping constant $\alpha(T)$ of Co_1Zn_1W hexaferrites. The $f_r(T)$ passes through a minimum near $T_2 = 80°C$ with increasing temperature. Further, this dependence has one more minimum at $T_1 = 130°C$. The $\alpha(T)$ also has features at these temperatures.

The temperatures at which $f_r(T)$ passes through the minimum correlate well with the SRPT EMP ↔ EMC (T_2) and EMC ↔ EMA (T_1) temperatures, obtained from neutron diffraction data. The damping constant α is maximum in the interval of the conical phase and decreases outside the SRPT region.

DISCUSSION

The anomalies observed in the temperature dependence of the NFMR frequency can be explained as follows. EMP state is implemented with an increase in the temperature up to $T \leq T_2$. In this region the MCA fields are related by the following inequalities: $H_{a1} < 0$ and $|H_{a1}| > H_{a2} + H_{a3}$. In this case $H_\Theta < 0$ and the resonance frequency is determined by (1).

The MCA field H_Θ changes sign at $T = T_2$. In the temperature range $T_2 \leq T \leq T_1$ the magnitude of the MCA field is $|H_{a1}| \leq H_{a2} + H_{a3}$. Therefore, the conical configuration (EMC) is energetically more favorable. A further increase in the temperature leads to the fact that at $T = T_1$ MCA field H_{a1} changes sign. Therefore, in the temperature range $T > T_1$ the EMA state is observed. The resonance frequency of the NFMR in this case is determined by (2).

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CONCLUSION

Thus, the behavior of the permeability spectra of the hexaferrites $Co_{2-x}Zn_xW$ system depending on the concentration of Zn^{2+} ions and temperature is explained by the NFMR theory. In this theory, it is considered that the main role in the processes of magnetization at microwave frequencies is played by the processes of rotation of the magnetization vector in the internal MCA fields.

An investigation of the permeability spectra allows additional information to be obtained not only about the behavior of the spin system in the vicinity of SRPT but also about the values and signs of the MCA constants of polycrystalline hexaferrites.

A change in the concentration of Zn^{2+} ions makes it possible to vary the resonance frequency of the NFMR of $Co_{2-x}Zn_xW$ hexaferrites in a wide range (by tens of times). This allows these materials to be used in devices operating in different microwave frequency ranges.

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