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Relaxation resonance in magnetic uniaxial crystal during transition from magnetically ordered to paramagnetic state

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Requirements are formulated that allow experimentally observation of the relaxation resonance in the thermal region of second order phase transition in ferromagnets. We show that these requirements can be fulfilled for highly anisotropic hexaferrites of structure type M in alternating magnetic field with frequency in the range 10–120 MHz.
Keywords: the relaxation resonance, a Curie point, phase transition, hexagonal ferrite.

Сформульовано умови, при виконанні яких у феромагнетиках можна експериментально виявити релаксаційний резонанс у температурній області фазового переходу другого роду. Показано, що ці умови можуть бути виконані для високоанізотропних гексаферитів структурного типу М у змінному магнітному полі в інтервалі частот 10–120 МГц.
Ключові слова: релаксаційний резонанс, точка Кюрі, фазовий перехід, гексаферит.

Сформулированы условия, при выполнении которых в ферромагнетиках можно экспериментально обнаружить релаксационный резонанс в температурной области фазового перехода второго рода. Показано, что эти условия могут быть выполнены для высокоанизотропных гексаферритов структурного типа М в переменном магнитном поле в интервале частот 10–120 МГц.
Ключевые слова: релаксационный резонанс, точка Кюри, фазовый переход, гексаферрит.

Introduction

The concept of spontaneous symmetry breaking is the basis for the theory of phase transition of the second kind [1]. Quantity theory was based on the self-consistent field approximation. While it was thought that the order parameter fluctuations are negligible. In [2, 3] it is shown that the fluctuations of the order, even if they are small far away from the transition point, become large near the phase transition. It was found that with the fluctuations increase, when approaching the phase transition point, there must be critical slowing-down of the relaxation parameter order. Theory of critical slowing-down was established in [4]. It was based on the phenomenological assumption that with the fluctuation nature of the phase transition, the critical dynamics of the order parameter is relaxing in nature. It has been shown that with such approval the relaxation time of order parameter τ, when approaching the temperature of transition T_C from lower temperatures, will increase as

$$\tau \sim \frac{1}{T_C - T}, \qquad (1)$$

where T_C – temperature of transition.

For ferro- and ferrimagnets, if the frequency of the external alternating magnetic field ω is less than the relaxation frequency $\omega_r = 1/\tau$ at temperatures T lower Curie temperature T_C, then at the Curie point approaching, in consequence of the critical slowing-down of the relaxation and growth velocity τ, the conditions $\omega\tau = 1$, that correspond to the relax resonance, can be realized [5]. The fact of relaxation response existence can be considered as experimental proof of critical slowing-down of the speed of relaxation order parameter at the fluctuation nature of the phase transition.

This paper outlines the conditions under which you can experimentally detect the critical slowing-down and relaxing resonance in the temperature range of the phase transition of the second kind in ferromagnets.

Magnetic susceptibility in magnetouniaxial crystal

In a multiple-domain magnetouniaxial crystal there are regions of the uniform magnetization – domains and transitional areas – domain boundaries. In highly anizotropic magnetouniaxial crystals domain boundaries volume is 10^3 times less than a volume of domains [6]. This fact suggests that if the orientation of the alternating magnetic field is the direction of easy magnetization the effect of domain boundaries on the processes of magnetization is oblique and their contribution to the magnetic susceptibility value can be neglected.

The equation of motion for the areas of a homogeneous magnetization $\vec{I}$ is [7]

$$\frac{\partial \vec{I}}{\partial t} = -\gamma\left[\vec{I}\times\vec{H}\right]+\vec{R} \qquad (2)$$

where $\vec{H}$ – is the effective magnetic field; γ – is the gyromagnetic ratio; $\vec{R}$ – relaxation term.

For the magnetouniaxial crystal with the orientation of the magnetic field $\vec{h}(t)$ and magnetization along the field of the anisotropy the first term on the right side of the expression (1) disappears and the order parameter – magnetization – becomes single. So, the expression (2) takes the form:

$$\frac{dI}{dt} = R, \quad R = \frac{I_p - I(t)}{\tau} \qquad (3)$$

where τ is the relaxation time; I_p – equilibrium value of the magnetization, corresponding to the magnetic field at time *t*; $I(t)$ – value of the magnetization, corresponding to the magnetic field at the time t.

The expression (1) is recorded in the model when the magnetization relaxes to the value I_p determined by the instantaneous field value $h(t)$. In this model $h(t)$ changes with frequency ω by the harmonic law

$$h(t) = h_0 e^{-i\omega t}, \qquad (4)$$

where h_0 is the amplitude value of the magnetic field.

In consequence of ultimate speed of magnetization processes, $I(t)$ is angle δ behind a phase of a magnetic field

$$I(t) = I_0 e^{-i(\omega t-\delta)}, \qquad (5)$$

where I_0 is the amplitude value.

Magnitude $I_p(t)$ can be represented as

$$I_p = \chi_0 h(t) = \chi_0 h_0 e^{-i\omega t}, \qquad (6)$$

where χ_0 is the static magnetic susceptibility when $\omega \to 0$.

From relationships (2) – (5) it should be

$$\chi_a e^{-i\delta} = \frac{\chi_0}{1-i\omega\tau}; \quad \chi_a = \frac{I_p}{h_0}. \qquad (7)$$

The expression (7) can be represented as

$$\chi' + i\chi'' = \frac{\chi_0}{1+\omega^2\tau^2} + i\frac{\chi_0\cdot\omega\tau}{1+\omega^2\tau^2}, \qquad (8)$$

where $\chi' = \chi_a \cos\delta$; $\chi'' = \chi_a \sin\delta$.

$$\chi' = \frac{\chi_0}{1+\omega^2\tau^2}; \quad \chi'' = \frac{\chi_0\cdot\omega\tau}{1+\omega^2\tau^2}. \qquad (9)$$

Dependences χ'/χ_0 and χ''/χ_0 from the ωτ under condition when the χ_0 is the constant value, are shown in

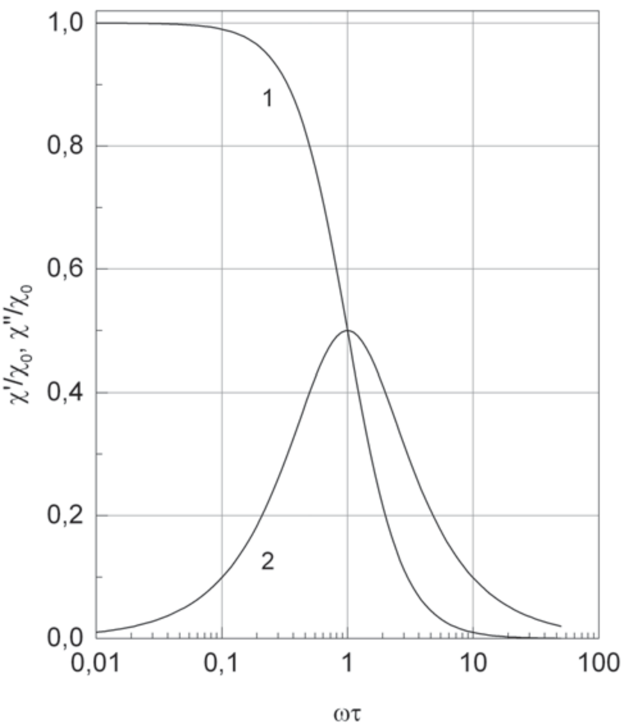

Fig. 1. The dependence of the variable part of the real and imaginary component of magnetic susceptibility on ωτ.

the figure. 1. As follows from the figure, the magnitude χ″, and consequently relaxation losses are maximal at ω τ =1. Increase of ωτ at fixed frequency and τ growth leads to a monotonous decrease of χ' and at $\tau \to \infty$ the value $\chi' \to 0$.

From the expression (1) it follows that the condition ωτ=1 of the relax resonance, you can reach within a narrow temperature range near the Curie temperature. However, for the sample of arbitrary shape and an arbitrary orientation relative to the external magnetic field, will depend on the temperature and intensity of a magnetic field. The condition χ_0=const can be achieved in a determined form magnetouniaxial crystal when demagnetizing field is uniform and oriented along the direction of easy magnetization [8]. In work [9] it is shown that for spherical single crystal gexaferrites with the orientation of the magnetic field along the direction of easy magnetization, the value χ_0 will be determined by the ratio

$$\chi_0 = 1/N = const, \qquad (10)$$

where $N = 4\pi/3$ is the demagnetizing factor of the sample.

The condition (10) occurs in magnetic fields $H < NI_S$ (I_S – magnetization of saturation).

In the Curie temperature T_C range the quantity I_S is small and therefore experiments must be realized for small values of $h(t)$.

Considered characteristics point to the principle possibility to detect the relaxation resonance and, respectively, critical slowing-down of relaxation parameter order in magnetouniaxial crystals under alternating magnetic field orientation along the direction of easy magnetization in crystals of a determined form at very small values of alternating magnetic fields. In addition to that for the temperature $T << T_C$ relaxation frequency $1/\tau$ must be greater than the magnetic field change frequency ω.

For hexaferrites of structural type M the width of the FMR curve is 16–80 Oe at room temperature [10, 11 , 12]. To this interval the interval of relaxation frequency 50-230 MHz corresponds. Therefore, the condition $\omega << \omega_r$ when $T << T_C$, can be realized in the radio-frequency range of external magnetic fields 10–120 MHz, when it is possible to use passive LC circuits for small magnetic fields making.

The considered features suggest the possibility to detect relaxation resonance and, accordingly, the critical slowing-down of relaxation of magnetization at highly anizotropic M type ferrites in the temperature range near the Curie temperature.

1. L.D. Landau. ZhJeTF, 7, 627 (1937) (in russian).
2. A. P. Levanjuk. ZhJeTF, 36, 810 (1959), (in russian).
3. V.A. Ginzburg. FTT, 2, 2031 (1960) (in russian).
4. L. D. Landau, N.M. Khalatnikov. DAN SSSR, 96, 469 (1954) (in russian).
5. Fizicheskij jenciklopedicheskij slovar'. Gl. red. A.M. Prohorov, redkol. D.M. Alekseev, A.M. Bonch-Bruevich, A.S. Borovik-Romanov i dr. M.: Sov. jenciklopedija (1984), s. 633(in russian).
6. S.V. Vonsovskij. Magnetizm. Izd-vo Nauka, 1971, 1032 s. (in russian).
7. L.D. Landau, E.M. Lifshic. «Jelektrodinamika sploshnyh sred», Moscow: Nauka (1982) (in russian).
8. G.S. Krinčik. Fizika magnitnyh javlenij. Izd-vo Mosk. un-ta, 1976, 367 p. (in russian).
9. A.A. Bezlepkin, S.P. Kuntsevich, S. P. Palekhin. „Izvestia Vuzov.Physika, N 7, 111 (1987) (in russian).
10. S. Dixon. J. Appl. Phys. 41, 1357 (1970).
11. J.A. Sweschnikow. Nachrichtentechn. Electronik, 26, 262 (1976).
12. A.A. Bezlepkin, S.P. Kuntsevich, V.I. Kostyukov. FTT, 30, N 1, 115 (1997) (in russian)