EQUATION OF THE FERROMAGNETIC RESONANCE LINE IN POLYCRYSTALLINE FERRITES

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Ferromagnetic resonance in polycrystalline ferrites is considered in the framework of the independent-grain model. It is shown that the ferromagnetic resonance absorption line can be obtained analytically from its moments. When a limited number of moments of the line are known explicitly, the method of Pearson curves is used to obtain the equation of the line. The obtained expression is analyzed and the resonance field and absorption line width deduced from the equation are compared with results obtained earlier.

To solve a number of problems associated with the further development of the theory of ferromagnetic resonance in polycrystalline ferrites and the practical use of these materials, it is necessary to know an equation for the absorption line. It is known experimentally that the resonance curves obtained from single-crystal and polycrystalline ferrites of nearly equal composition are very different. Whereas the former can be fairly well described by a Lorentzian curve, the latter usually have a substantial line width, are asymmetric with respect to the resonance field, and sometimes have a complicated structure. A complicated line structure is characteristic of porous semicrystalline materials with large magnetic anisotropy, for which the independent-grain approximation is valid [1, 2]. The difficulty in obtaining an equation for the absorption line is due in the first place to the circumstance that the density of the distribution of the resonance fields of the crystallites, W(H), which is adopted in this approximation as the resonance curve of the polycrystalline sample, gives only a schematic, simplified image of the absorption line. The function W(H) is essentially asymmetric and has analytic singularities — discontinuities of finite magnitude at the beginning and end of the interval of fields, where it is nonzero, and it becomes infinite in accordance with a logarithmic law at the resonance [1]. Because of the existence of other broadening mechanisms not associated with the anisotropy, and the nonvanishing line width of the individual crystallites, these features are manifested in a very smeared form experimentally.

In [3, 4], the density of the distribution of the resonance fields was approximated by a Lorentzian curve and a Gaussian curve, and the absorption line width calculated on this basis. From the point of view of obtaining an equation for the resonance curve, such an approximation of W(H) cannot be regarded as felicitous, since it disregards the asymmetry of the line, which is an important feature. In the present paper, the equation of the absorption line is found using the moments of the density of the distribution of the resonance fields of the crystallites, W(H), on the basis of Pearson curves [5]. The use of the methods of mathematical statistics is natural, since the fields produced by the magnetic anisotropy have a random nature because of the random orientation of the crystallographic axes of the crystallites. We note that the method of moments was also used in [6] to describe the dynamic susceptibility of superparamagnets.

1. Moments of the Absorption Line

It can be shown (see [7]) that in the independent-grain approximation the calculation of the initial (relative to zero field) moments \( m_l \) of the ferromagnetic resonance line reduces to averaging of the corresponding powers of the resonance field \( H_0(\Theta, \Phi) \) of an individual crystallite, i.e.,

\[
m_l = \overline{H_0^l(\Theta, \Phi)},
\]
where $\Theta$, $\Phi$ are, respectively, the polar and azimuthal angles of the vector of the static magnetic field in the spherical coordinate system whose polar axis coincides with the [001] direction, the angle $\phi$ being measured from [100]. The bar denotes averaging over these angles.

Assuming that the magnetic anisotropy is not too large, but is sufficient for the independent-grain approximation to hold, we represent $H_0(\Theta, \Phi)$ as a series in powers of the small parameter $\kappa$, which is the ratio of the effective anisotropy field $H_0 = 2\kappa / M$ ($\kappa$ is the first constant of the magnetic crystallographic anisotropy, and $M$ is the saturation magnetization) to the resonance field for a spherical sample in an isotropic medium, $\omega / \gamma$ ($\omega$ is the circular frequency of the electromagnetic radiation, and $\gamma$ is the gyromagnetic ratio):

$$H_0(\Theta, \Phi) = \omega \left[ 1 + a_1 \kappa + a_2 \kappa^2 + \ldots \right] / \gamma.$$  \hspace{1cm} (2)

In accordance with (2), we shall also seek the moments of the absorption line as power series in $\kappa$. To find an equation for the ferromagnetic resonance line, we need the central moments $m_l$, which are related to $m_l$ by

$$\mu_l = \sum_{q=0}^{l} (-1)^q \frac{l!}{q!(l-q)!} m_{l-q}.$$

After substitution of (2) in (1) and the use of (3), we obtain for the first three moments, which are needed to describe an asymmetric resonance curve,

$$m_1 = (\omega / \gamma) \left[ 1 + a_1 \kappa + a_2 \kappa^2 + \ldots \right], \quad m_2 = (\omega / \gamma)^2 \left[ (a_1 - a_1)^2 \kappa^2 + 2(a_2 - a_2) \kappa^3 + \ldots \right], \quad m_3 = \frac{(\omega / \gamma)^3}{1} \left[ (a_1 - a_1)^3 \kappa^3 + 3(a_2 - a_2) \kappa^3 + \ldots \right].$$

The mean values of the functions $a_1$ and $a_2$ in (4) were found earlier by us in [7]. Under the assumption that the crystallites in the sample have equally probable orientations, we obtain for (4)

$$m_1 = \omega / \gamma (1 - 29/105 \kappa^2), \quad m_2 = 4/21 H_0^2 (1 - 441/715 \kappa), \quad m_3 = 48/1001 H_0^2 (1 + 257/630 \kappa).$$

2. Resonance Absorption Line

To recover the ferromagnetic resonance line from its moments, we must in general know all the moments. Then, using the formula

$$G(t) = e^{i\omega t} \sum_{l=0}^{\infty} (it)^l \mu_l / l!$$

we can calculate the relaxation function (the antiderivative function) $G(t)$, which is the Fourier transform of the absorption line (see [8, 9]) ($g(H)$):

$$g(H) = \frac{1}{2\pi} \int_{-\infty}^{\infty} G(t) e^{-iHt} dt.$$  \hspace{1cm} (8)

In the first approximation, taking into account the terms linear in $\kappa$ in the expansion of the resonance field, we obtain for the $l$-th central moment

$$\mu_l = (\omega / \gamma)(a_1 - a_1)^l \kappa^l.$$

Reversing the order of summation and integration in (7), we can write $G(t)$ in the form

$$G(t) = \exp \left[ t(\omega / \gamma)(1 + a_1 \kappa) / t \right].$$

Note that $G(t)$ does not vanish in the limit $t \to \infty$. The reason for this is that we have