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DOMAIN FORMATION IN FERROMAGNETIC FILMS INCLUDING MAGNETOELASTIC EFFECTS

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Abstract. - Static and dynamic properties of a thin ferroelastic film near the phase transition from the state of homogeneous magnetization and deformation to the state of domain and modulated structures are considered. The phase transition is caused by a change of external magnetic field. Formulae describing magnetic and magnetoelastic susceptibility tensors are derived and discussed.

The aim of this paper is to describe static and dynamic magnetoelastic properties of a thin ferromagnetic film near the phase transition from the state of homogeneous magnetization and homogeneous deformation to the state with domain and modulated structures. Let us consider a thin film of thickness $L$ made of uniaxial ferromagnet with the easy magnetization axis perpendicular to the surfaces of the film and parallel to the $z$-axis of the Cartesian coordinate system.

Let us assume that the anisotropy energy of the material is less than the maximum value of the demagnetizing energy. In such kind of films for the film thickness $L < L_c$ the ground state is the state of homogeneous magnetization in the film plane, i.e. in the hard magnetic direction. The symbol $L_c$ denotes the critical thickness of the film for which there is the phase transition [1, 2] from the homogeneous magnetization state to the domain structure which is the ground state for $L > L_c$. A film of thickness $L > L_c$ undergoes this transition at a critical value of an external magnetic field lying in the film plane $H_s^*(L)$.

The energy of the film is described [3] by the functional:

$$F = \int_V \frac{1}{2} M^2 \left[ \alpha (\nabla m)^2 - \beta m^2 - h^d m - 2hm^2_y \right] +$$

$$+ B_1 (e_{xx} + e_{yy}) m^2 + B_3 e_{zz} m^2$$

$$+ \left( B_{11} m^2 + B_{12} m^2_y \right) e_{xx}$$

$$+ \left( B_{12} m^2 + B_{11} m^2_y \right) e_{yy} + B_{33} m^2 e_{zz}$$

$$+ 2B_{44} (m_z m_x e_{yz} + m_z m_y e_{zx}) + 2B_{66} m_x m_y e_{xy}$$

$$+ \frac{1}{2} C_{11} \left( e_{xx}^2 + e_{yy}^2 \right) + C_{12} e_{xx} e_{yy}$$

$$+ C_{13} (e_{xx} + e_{yy}) e_{zz} + \frac{1}{2} C_{33} e_{xx}^2$$

$$+ 2C_{66} e_{xx}^2 + 2C_{44} \left( e_{yy}^2 + e_{xy}^2 \right) \right\}$$

(1)

where

$$m = M_0^{-1} M,$$

$$e_{ij} = \frac{1}{2} (u_{i,j} + u_{j,i}),$$

$$h = M_0^{-1} H_s^*, \quad h^d = M_0^{-1} H^d.$$ (2)

The symbol $h^d$ denotes the vector of reduced demagnetizing field connected with the reduced magnetization vector $m$ via Maxwell’s equations:

$$\xi_{ijk} h^d_{j,k} = 0, \quad h^d_{i,i} + 4\pi m_{i,i} = 0.$$ (3)

Let us assume that the ground state is the state of homogeneous magnetization $m^0_i$ and homogeneous deformation $e^0_{ij}$ determined by:

$$m^0_i = (0, 1, 0), \quad \delta F/\delta e_{ij} \bigg|_{e_{ij} = e^0_{ij}} = 0.$$ (4)

The excitations $\mu_i (r, t)$ and $e_{ij} (r, t)$ are defined as follows:

$$\mu_i (r, t) = m_i (r, t) - m^0_i, \quad e_{ij} (r, t) = e_{ij} (r, t) - e^0_{ij}.$$ (5)

In the case of strong magnetic surface anisotropy and traction free surfaces the boundary conditions have the form:

$$\mu_z |_{z = \pm L/2} = n_i, \quad \delta F/\delta e_{ij} |_{z = \pm L/2} = 0,$$ (6)

where $n_i$ is the vector perpendicular to the film surfaces. From an examination of the energy of magnetic and elastic excitations in the $q$ representation, it follows [4] that the postulated ground state is stable if

$$\Delta_0 \approx M_0^4 \alpha (4\pi - \beta^2) \times$$

$$\times \left[ q_0^2 (q_0 - q_0/q)^2 + \xi^{-2} (h) \right] > 0$$ (7)

where $q_0 = (q_0, \alpha, \pi L^{-1})$ and

$$q_0^2 = 2\pi \left[ \frac{\pi \beta^*}{\alpha (4\pi - \beta^2 + 2h)} \right] L^{-1},$$

$$\xi (h) = \left[ \frac{\alpha}{\beta^*} \right] L^{-1/2} \left[ \frac{h_c}{h - h_c} \right]^{1/2}$$ (8)

The symbol $\beta^*$ denotes the renormalized anisotropy constant. The function $h_c (L)$ defines the phase boundary,

$$h_c (L) = \beta^* - 4\pi \left[ \frac{\pi \alpha \beta^*}{4\pi + \beta^*} \right]^{1/2} L^{-1}.$$ (9)
For \( h = h_c (L) \) and \( \mathbf{q} = \mathbf{q}_0 \) there is a phase transition from the homogeneous magnetization state to the domain structure with an initial period \( \lambda_0 = 2\pi q_0^{-1} \) along the \( x \)-axis.

The motion equations have forms \([5]\):

\[
\rho \ddot{u}_i = \sigma_{ij,j} + \gamma_{ij,j} \tag{10}
\]

\[
\rho \ddot{u}_i = \sigma_{ij,j} + \gamma_{ij,j} \tag{11}
\]

where \( \omega_0 = gM_0 \) and

\[
h_i^{\text{ef}} = M_0^{-1} \delta F/\delta m_i, \quad \sigma_{ij} = \delta F/\delta \epsilon_{ij}, \quad \gamma_{ij} = \eta_{ijkl} \partial \epsilon_{kl}/\partial t. \tag{12}
\]

The damping tensor \( \eta_{ijkl} \) has the same structure as the elastic stiffness tensor \( C_{ijkl} \). Solutions of the set of motion equations (10, 11) should fulfil the Maxwell's equations (3) and boundary conditions (6).

It has been shown \([4]\) for undamped dispersion relations, that there exists a quasi-acoustic soft mode corresponding to the structural phase transition if the quasi equilibrium condition \( \delta F/\delta \epsilon_{ij} = 0 \) is fulfilled. In this case the magnetic susceptibility tensor \( \chi^{\text{me}}_{ij}(\mathbf{q}, \omega) \) has the form:

\[
\chi^{\text{me}}_{xx}(\mathbf{q}, \omega) = - \left[ (1 + \tau^2) \delta_{xx}(\mathbf{q}) - i\tau \omega \right] \delta_{x}^{-1}(\mathbf{q}, \omega),
\]

\[
\chi^{\text{me}}_{zz}(\mathbf{q}, \omega) = - \left[ (1 + \tau^2) \delta_{zz}(\mathbf{q}) - i\tau \omega \right] \delta_{x}^{-1}(\mathbf{q}, \omega),
\]

\[
\chi^{\text{me}}_{xz}(\mathbf{q}, \omega) = \left[ (1 + \tau^2) \delta_{xz}(\mathbf{q}) - i\tau \omega \right] \delta_{x}^{-1}(\mathbf{q}, \omega),
\]

\[
\chi^{\text{me}}_{xy}(\mathbf{q}, \omega) = \left[ (1 + \tau^2) \delta_{yz}(\mathbf{q}) - i\tau \omega \right] \delta_{x}^{-1}(\mathbf{q}, \omega),
\]

where

\[
\delta_{xx}(\mathbf{q}) = aq^2 + 4\pi q^2 q^2 - h,
\]

\[
\delta_{zz}(\mathbf{q}) = aq^2 + 4\pi q^2 q^2 - \beta^2 + h.
\]

The susceptibility tensors (13, 17) are singular at the phase transition point \( \omega = 0, h = h_c (L) \) and \( \mathbf{q} = \mathbf{q}_0 \). It means that simultaneously with the appearance of the domain structure there develops the modulated structure of the displacement vector. From an examination of magnetoelastic excitations it follows that they are overdamped near the phase transition point. Excitations parametrized by the vector \( \mathbf{q} = \mathbf{q}_0 \) relax most slowly and become unstable at the phase transition point \( h = h_c (L) \). It corresponds to the nucleation of domain and modulated structures.

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\[ [1] \text{Hubert, A., Theorie der Domänenwände in Geordneten Medien (Springer Verlag, Berlin) 1974.} \]


\[ [5] \text{Akhiezer, A. I., Baryakhtar, W. G. and Paletminsky, S. W., Spin Waves (North Holland, Amsterdam) 1968.} \]