THEORY OF SPIN-REORIENTATION IN FERROMAGNETIC NANOSTRUCTURES AND CORRESPONDING DOMAIN CONFIGURATIONS

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In an bulk magnetic crystal values of magnetic (magnetocrystalline) anisotropies are determined by magnetic interactions in the ideal crystalline structure and reflect its symmetry. Contrary to these intrinsic anisotropies, in magnetic nanostructures extrinsic anisotropies arise as the result of various physical and chemical modifications due to the presence of surfaces and interfaces. The effective magnetic anisotropy of films with induced out-of-plane anisotropy depends nonlinearly and nonmonotonically on film thickness, this is at variance with the predictions of Neel's theory [1].

In our article we user a new phenomenological theory that gives a consistent description of the induced magnetic anisotropy in perpendicular magnetic layers, out of Neel's approximation [2]. According to this theory, contrary to the case of bulk materials, coefficients of induced magnetic anisotropies in nanostructures should be treated as internal variables. Modern depth-resolved experimental techniques show that the surface-induced magnetic anisotropy is not strictly confined to the surfaces or interface but extends into the depth of magnetic layers.

Within a phenomenological theory, we assume that, the possible distribution can be described by an inhomogeneous "order parameter" – field derived from general interaction functional:

$$\Phi = -\mathrm{sgn}(K)\cos^4\theta + (1-k)\cos^2\theta - h\cos(\theta-\psi) \qquad (1)$$

with k(d)=B(d)/(2K), $h = H|M|/(2K)$ - internal field; θ-angels between z and the magnetization vector m(H).

(Easy axis a, magnetization vector m and effective field share a common plane.)

The energy (1) is mathematically equivalent to the phenomenological energy of a bulk ferromagnet, where variations of the second-order anisotropy constant with temperature or pressure cause a reorientation of the easy magnetization direction [2] and results for these systems can be used to describe the phase structure of homogeneous states in magnetic nanolayers.

The equilibrium distribution energy – density of the induced uniaxial anisotropy are obtained by independent minimization of interaction functional $\omega_a = \alpha\left(\frac{dB}{dz}\right) + aB^2$:

$$B(z) = B1\frac{\cosh(2z/d)}{\cosh(d/\delta)} \qquad (2)$$

where B1 – a phenomenological constant/

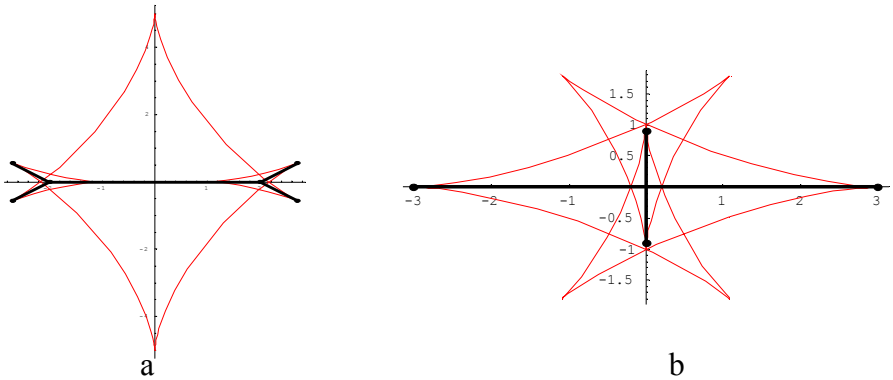
The distribution B(z) (2) dependents on the relation between values of the layer thickness d and a characteristic length $\delta = 2\sqrt{\frac{\alpha}{a}}$.

Analysis of magnetization curves, shows that for thick films the profiles B(z) have finite values only in close vicinity to the layer surfaces and decrease exponentially into the depth of the layer, and for thin films the functions B(z) have considerable values within all the layer.

The equilibrium states are obtained by independent minimization of functional (1). This states depend on the parameter k that describes the variation of the effective anisotropy with thickness. The stability limits represented parametric equations:

$$\begin{cases} h_x = 2\sin^3\theta(k + \mathrm{sgn}(K)(5 - 6\sin^2\theta)) \\ h_z = 2\cos^3\theta(-k + \mathrm{sgn}(K)(5 - 6\cos^2\theta)) \end{cases} \qquad (3)$$

Combined equations (3) described of the modified system Stoner – Wohlfarth.
In Figs.1 the $h_x h_z$ phase diagrams are given for various value of effective anisotropy k. The lines of first –order transitions between the co-existing phases presented extraheavy lines.

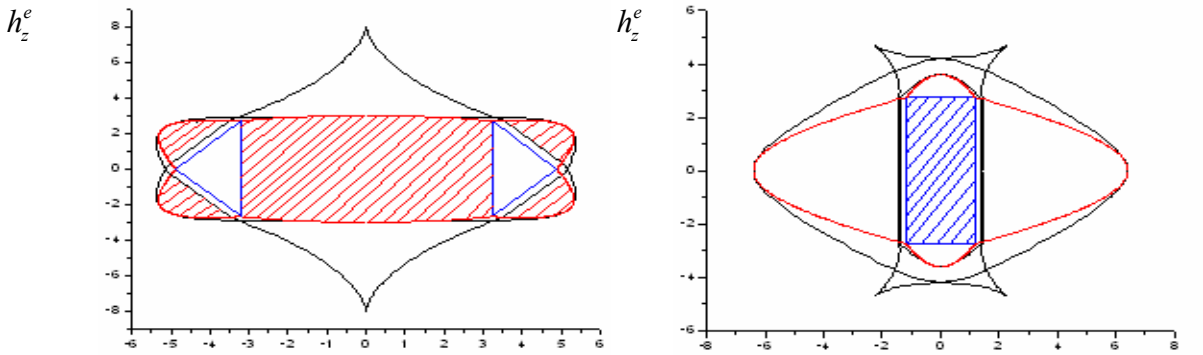


a b

Fig. 1. Phase diagrams for 0<k<5. (a – K>0; b – K<0).

The first – order transitions between magnetic state are accompanied by thermodynamicall stable multidomain states built from the co – existing phases [3]. Depending on the number of phases two-, three- and four – phase multidomain patterns will arise. (two-, three- and four – phase – K>0; two-, four – phase – K<0).

In Figs. 2 the $h_x^e h_z^e$ phase diagrams in components of the external field are given.



a b

Fig.2. $h_x^e h_z^e$ phase diagrams. (a - shaded area corresponded two- phase domain structure, area of triangle corresponded three- phase domain structure K>0; b - shaded area corresponded four- phase domain structure K<0).

References.

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