EFFECT OF SUPERCONDUCTIVE COVER ON FERROMAGNETIC DOMAIN STRUCTURE

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This work deals with two-layer structures, consisting of an easy-axis ferromagnetic with the flat-parallel domain structure and a superconductor, located in the constant external magnetic field. Dependence of the flat-parallel domain structure magnetic moment on the external field is derived and differential susceptibility of a ferromagnetic is calculated. It is shown that the superconductive film on the ferromagnetic substrate with flat-parallel domain structure changes the dissipation field configuration and reduces the ferromagnetic differential susceptibility.

In connection with discovery of high-temperature superconductivity (HTSC), the interest in two-layer structures, consisting of ferromagnetic and superconductive films has grown [1,2]. These structures are of practical interest from the standpoint of EHF as magnetostatic wave amplifiers, if there the magnetic vortex flux is directed in superconductors, which are formed in the external magnetic field [3,4].

The aim of this paper is to study an effect of the superconductive cover on the domain structure in ferromagnetic films.

Let's consider the two-layer structure, consisting of easy-axis ferromagnetic and superconductive films, located in the constant external magnetic field H_0 parallel to OZ axis. Full energy to two-layer structure, standardized on value $2\pi h M_s L_x L_y$, can be considered as a sum :

$$U = U_f + U_s + U_{sf}. \tag{1}$$

Where U_f — free energy of a ferromagnetic film; U_s — free energy of a superconductive film; U_{sf} — energy of interacting ferromagnetic and superconductive films; M_s — saturation magnetization ; h — thickness of a ferromagnetic film; L_x — distance along OX-axis, L_y — distance along OY-axis.

For simplicity let's consider only the case, when the effect of superconductive cover does not twist domain borders and vortices in a superconductor which don't interact. Consequently, this model is correct in the vicinity of induction values $N\lambda^2 << 1$, where N — the vortex density per unit area, λ — depth of the magnetic field penetration. It is also assumed that dissipation fields H_μ penetrate freely into superconductive films as the demagnetized factor for the infinite superconductive film equals to unity [5]. Then, non-measured free energy of a ferromagnetic film with the flat-parallel domain structure can be written down as [6]:

$$U_f = \frac{4l}{D} - 2MH_0 + M^2 + \frac{4D}{\pi^3}\sum_{n=1}^{\infty}\frac{R(n,D)}{n^3}\sin^2(Q(n,M)). \tag{2}$$

Here, the following non-dimensional variables are introduced:

$$R(n,D) = 1 - \exp(-2\pi n/D); \quad Q(n,M) = \pi n(1 + M)/2, \tag{3}$$

where M — magnetization of a ferromagnetic, D — period of the domain structure, l — characteristic length of a ferromagnetic material [7].

Let's use the Gibb's thermodynamic potential for calculation the free energy of a superconductive film [5]:

$$G = G_0 + NE - BH/4\pi \,, \tag{4}$$

where

$$E = \left(\frac{\Phi_0}{4\pi\lambda}\right)^2 \left(\ln (\lambda/\xi) + \varepsilon\right) . \tag{5}$$

Here, E — vortex energy per unit length ; B — magnetic induction in a superconductor; Φ_0 — a quantum of magnetic flux; H — external field; ξ — length of coherency.

Here we shall take into consideration the interaction through the magnetostatic field of a ferromagnetic H_μ [7]. Then, using the formula

$$B = N\Phi_0 \tag{6}$$

and the fact that the external field is the superposition of fields

$$H = H_0 + H_\mu \,, \tag{7}$$

we determine the vortex density per unit area :

$$N = B/\Phi_0 \,. \tag{8}$$

Substituting into equality (4) H, N and integrating we get:

$$U = U_s + U_{sf} \,, \tag{9}$$

where U_{sf} — energy of interaction of ferromagnetic and superconductive films with the aid of dissipation fields.Carrying out proper calculations, we obtain:

$$U_{sf} = \frac{W}{\pi^2}\sum_{n=1}^{\infty}\frac{R(n,D)}{n^2}\left\{\sin^2 (Q(n,M)) + \frac{1}{2}\left[\cos(\pi n) - \cos(\pi n(2+M))\right]\right\} -$$
$$-\sum_{n=1}^{\infty}\left[W_1 + \frac{W_2}{4\pi n}\right]\frac{R^2(n,D)}{n^2}\sin^2\left(Q(n,M)\right)\left[\sin(\pi n(3-M)) + \sin(2Q(n,M))\right] ;$$
$$W = \frac{Eh_s}{\Phi_0 hM_s} - \frac{2h_sH_0}{h} ; \quad W_1 = \frac{h_s + 2\lambda}{\pi^2 h} ; \quad W_2 = \frac{h_s - 2\lambda}{\pi^2 h} \,, \tag{10}$$

h_s — thickness of a superconductive film.

Adding up (2), (9), we obtain full energy of a two-layer structure:

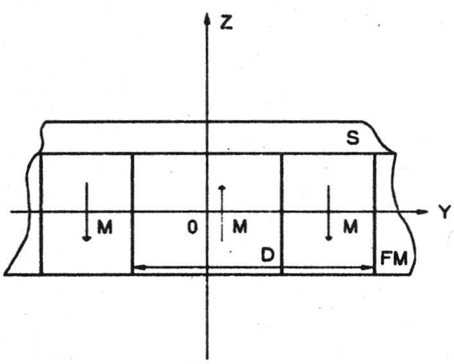
$$U = \frac{4l}{D} - 2MH_0 + M^2 + \frac{4D}{\pi^3}\sum_{n=1}^{\infty}\frac{R(n,D)}{n^3}\sin^2\left(Q(n,M)\right) + U_s +$$
$$+ \frac{W}{\pi^2}\sum_{n=1}^{\infty}\frac{R(n,D)}{n^2}\left\{\sin^2\left(Q(n,M)\right) + \frac{1}{2}\left[\cos(\pi n) - \cos(\pi n(2+M))\right]\right\} -$$
$$-\sum_{n=1}^{\infty}\left[W_1 + \frac{W_2}{4\pi n}\right]\frac{R^2(n,D)}{n^2}\sin^2\left(Q(n,M)\right)\left[\sin(\pi n(3-M)) + \sin(2Q(n,M))\right] . \tag{11}$$

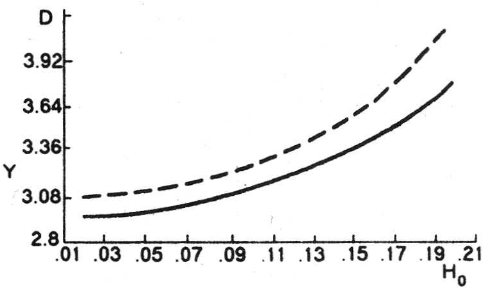
From the condition of minimum (11), for typical values $M_s \sim 100$ Гс, $l \sim 0.1$, $h_s/h \sim 0.1$ and $h_s/\lambda \sim 3$, $\xi \sim 10^{-7}$ cm, $\lambda \sim 10^{-5}$ cm where data for HT SC are taken from [8] for $T \sim 77$ K, we find quantitatively the period and difference of periods of the domain structure, as a function the external magnetic field.

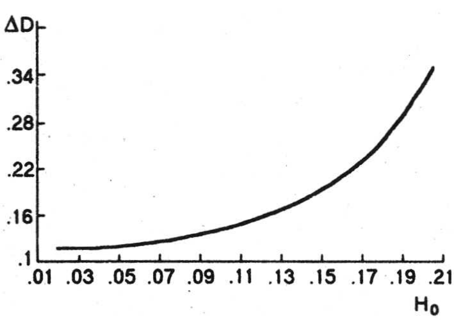
Using equality (11) featuring the free energy of a two-layer structure we calculate the domain — structure's susceptibility as a function of the external field:

$$\chi = \frac{\partial M}{\partial H}. \tag{12}$$

Let's consider the case when D = const. Carrying out the analogous calculation and using the same values [8], we find quantitatively the domain structure's susceptibility, as a function of the external field (Fig. 4).







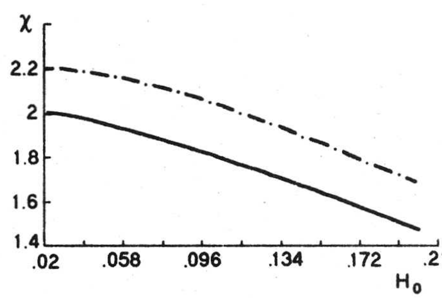


Fig. 1. The two-layer structure: S — superconductive film; FM — ferromagnetic film

Fig. 2. The dependence of the period of the domain structure of a ferromagnetic film on the external magnetic field. Unbroken line — two-layer structure; dotted line — ferromagnetic film

Fig. 3. The dependence of the difference of periods of the domain structure of a ferromagnetic film with and without the superconductive cover on the external magnetic field

Fig. 4. The dependence of susceptibility domain structure of ferromagnetic film with and without superconductive cover on the external magnetic field

Thus, from Figs. 2, 3 and 4 we can see that the superconductive cover, which reduces a period of the domain structure, vitally affects a period of the domain structure of a ferromagnetic. It deals with a change of the dissipation field configuration of a ferromagnetic film in the system under consideration and, as the numerical analysis shows, a change of the period ΔD is directly proportional to the thickness of a superconductivity film, under condition $\lambda < h_s < h$.

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