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STUDYING OF THE BEHAVIOR AND PROPERTIES OF A PERIODIC RING DOMAIN STRUCTURE

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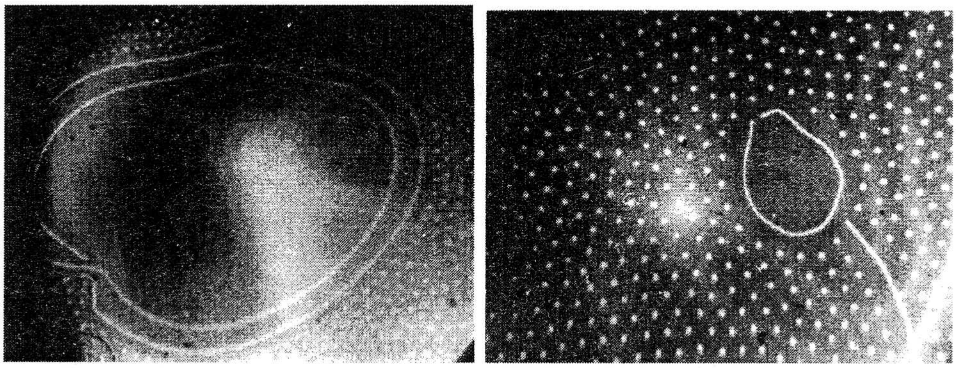
Ring domain structures (RDS) being the system of the alternative concentric rings appear in the ferrite-garnet films under the action of a low-frequency magnetic field along with the spiral domain structures. The theoretical calculation of the total ring domain structure energy has been made by the method of magnetic charges, so that magnetization of the film has been simulated by means of generalized functions. Dependencies of RDS energy on film characteristic length, on DS parameters and on external field are represented. The calculated results show that the equilibrium RDS may exist in the case of the small number of rings. The comparison of presented result with the energy of the spiral domain structure has been carried out.

In references [1,2] they inform of the case of a special excited state of ferrite-garnet uniaxial film which occurs at a low-frequency pumping and is accompanied by the formation of a stable formate dynamic domain structure (DDS) with appropriate geometry. So, the contrast DDSs are formed in some amplitude interval at the frequency equal $f = 120 - 200$ Hz and they consist of the concentric ring systems. The experimental and theoretical studying of a spiral domain configurations (SpDS) in thin ferrite-garnet films done by us in [3,4] made us to study the ring domains. The experimental results have shown that in the uniaxial films of the $(TmBi)_3(FeGa)_5O_{12}$ composition grown with the liquid-phase epitaxy method on the GGG substrate with the (111) orientation the groups consisting of 1-3 concentric rings may occur. These groups might occur between cylindrical domains which can be represented both as a regular lattice and an amorphous structure (Fig. 1).

The present work is devoted to the theoretical studies of the static properties of concentric rings and the research of the behavior of their total internal energy.

Let us solve the magnetostatic problem for a common case of a big number of rings. In this case the domain structure is the system of N concentric rings and the distribution of the magnetization within the film is as follows:



a *b*

Fig. 1. The ring domains

$$M_z = M\Theta\left(\frac{h}{2}+z\right)\Theta\left(\frac{h}{2}-z\right)\left[1-2\sum_{n=0}^{N}\Theta(r-R_0-pn)\Theta(a-r+R_0+pn)\Theta(\varphi)\Theta(2\pi-\varphi)\right], \qquad (1)$$

where r,φ,z – the cylindrical coordinates, $\Theta(x)$ – the staged Heaviside function, p - the domain structure period, N - the numbers of rings, R_0 is the initial radius. To get the expression for the magnetostatic energy E_m we use the magnetic charge method, described in [5], so that

$$E_m = \frac{1}{2}\int_V \rho\psi dV, \qquad (2)$$

where $\rho = -div\vec{M}$ and $\Delta\psi = -4\pi\rho$ (ρ is the density of magnetic charges. Having solved the corresponding magnetostatic problem we obtain the rigorous expression for the magnetostatic energy Em

$$\frac{E_m}{2\pi M^2} = \left[1-4\frac{a}{p}\left(1-\frac{R_0}{R}\right)\left(1+\frac{R_0+a-p}{R}\right)\right](\pi R^2 h)+$$

$$\frac{32i}{\pi^4}(\pi R^2 h)\int_0^1 y\left(\frac{\pi a}{2p}+\sum_{n=1}^{\infty}\frac{\sin(\eta_n)\cos(\mu_n(y)-\eta_n)}{n}\right)\sum_{m=-\infty}^{\infty}\frac{e^{i\mu_m(y)}(e^{-i\eta_m}-1)}{m}G(y,m)dy \qquad (3)$$

Here we introduce the following denominators

$$\mu_n(y) = \frac{2\pi R}{p}n\left(y-\frac{R_0}{R}\right),\ \eta_n = \frac{\pi a}{p}n,\ \mu_m(y) = \frac{2\pi R}{p}m\left(y-\frac{R_0}{R}\right),\ \eta_m = \frac{\pi a}{p}m,$$

$$G(y,m) = \int_0^{\infty}\frac{\sin^2(\pi k)}{k^2}\frac{1-\exp\left(-\sqrt{\left(\frac{2\pi h}{p}m\right)^2 - i\frac{2\pi h^2}{pR}\frac{m}{y}+\left(\frac{kh}{yR}\right)^2}\right)}{\sqrt{\left(\frac{2\pi h}{p}m\right)^2 - i\frac{2\pi h^2}{pR}\frac{m}{y}+\left(\frac{kh}{yR}\right)^2}}dk,$$

$y = r/R$, R is the structure size, h - the film thickness.

Let's consider that domain walls are pure Bloch ones, and the energy of the domain walls can be written as

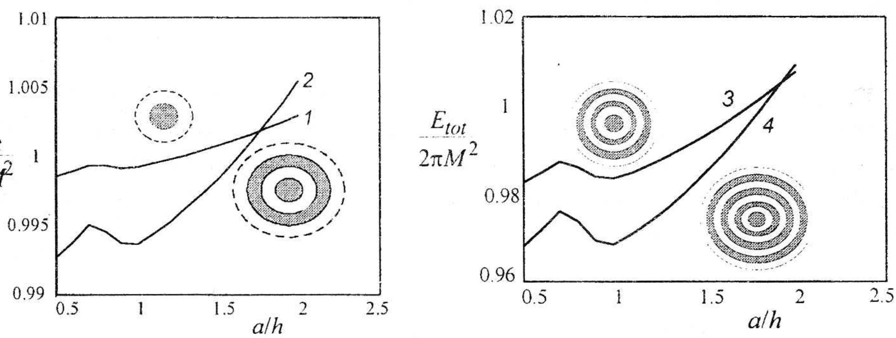
$$\frac{E_{dw}}{2\pi M^2} = 4\frac{l}{p}\left(1-\frac{R_0}{R}\right)\left(1+\frac{R_0+a-p}{R}\right)(\pi R^2 h) \qquad (4)$$

The energy of interaction with the external magnetic field $\tilde{H} = H/(4\pi M)$ equals

$$\frac{E_h}{2\pi M^2} = -2\tilde{H}\frac{a}{p}\left(1-\frac{R_0}{R}\right)\left(1+\frac{R_0+a-p}{R}\right)(\pi R^2 h) \qquad (5)$$

So summing up the expressions (4), (6) and (7) we obtain the expression for the total RDS energy E_{tot}.

Let us now investigate the behavior of the ring structure for various geometrical parameters. The dependence of the density of the total energy of the ring domains on the ring width a/h is given in Fig.2(*a*,*b*). In this case the initial radius R_0/h equals zero, the film dimension is $R/h = 50$ and the dimension of the region occupied by ring domains is r = 2,4 (in Fig. 2*a* curves 1 and 2, respectively) and r = 6,8 (curves *3* and *4* in Fig. 2*b*). While using this calculation method one assumes that the film part which is not occupied by the domains is in a monodomain state. So, in spite of the fact that we do not take into consideration the energy of external magnetic field and assume $p = 2a$, in fact we consider the rings under the strong magnetic field.



a *b*

Fig. 2 Dependence of the density of total energy of the ring domains on ring width a/h : *1* - $r/h = 2$; *2* - $r/h = 4$; *3* - $r/h = 6$; *4* - $r/h = 8$. The film dimension is $R/h = 50$

The curve 1 in Fig. 2(*a*) has one minimum at $a/h = 1$ for the region with radius $r/h = 2$. Judging from the geometry of the structure it follows that $r/h = 2N\cdot(a/h)$ .Consequently the cylindrical domain with the radius $a/h = 1$ is in the region center. The comparison, as test, of the given particular case with the results of the [6-8] works, where bubbles were investigated in some symmetric fields, allows us to confirm that the presented calculation method gives qualitative as well as quantitative true value of the internal energy of ring domains.

The curve 2 in Fig.2(*a*) has one minimum at point $a/h = 1$. It means that the film region with radius $r/h = 4$ has a bubble in the center and around it there is a ring with the width $a/h = 1$. In Fig.2(*b*) the analogous dependencies for the regions with sizes $r/h = 6$ and $r/h = 8$ are shown. The equilibrium structure corresponding to, for example, the calculation curve 3 consists of the bubble and two concentric rings with the width $a/h = 1$. The existence of the energy minima of the ring domain structure on a monodomain state background indicates the possibility of realization of systems consisting of 2-6 rings in strong magnetic fields as was shown in experiments [1,2].

In Fig.3 the dependencies for the density of the energy of the demagnetized ring, spiral [4] and stripe domain structures in approximation of a large number of winds (for spiral) and rings (for ring DS) are shown.

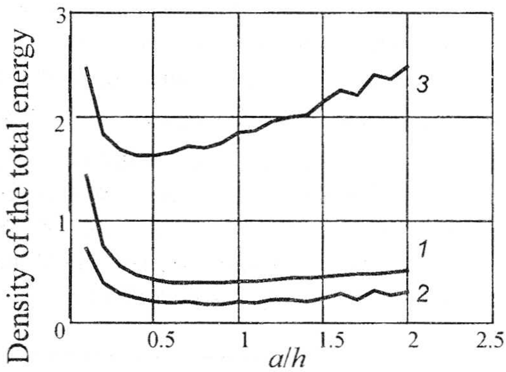


Fig.3 Dependencies for the density of the energy of demagnetized stripe (*1*), spiral (*2*) and ring (*3*) domain structure on the structure parameter $-a/h$. The film dimension is $R/h = 50$

The comparison of these curves indicates that the demagnetized ring DS is not realized in demagnetized state in spite of the fact that it is the most compact one from the point of view of geometry. We believe that it is connected with the existence of the dipole-dipole repulsion between the ends of stripe which should be overcome to create a similar multiring structure.

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