Influence of a magnetic suspension on the domain structure and domain walls in thin ferromagnetic films

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The powder figures produced on demagnetized Permalloy and 79 NMA films ~200–600 Å thick were investigated under different conditions, namely in the presence and absence of a magnetic suspension (MS). It is shown that the presence of the MS influences the domain structure and the domain walls.

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The Akulov-Bitter method, in which a magnetic suspension (MS) is used, has received wide recognition and extensive use for the investigation of the domain structure of magnetic materials.[1] The literature, however, does not consider the question whether an MS can influence the domain structure and the domain walls, i.e., whether the MS is a source of instrumental distortions. It seems to us that this instrumental effect is possible in weakly anisotropic thin films, where the role of the stray fields at the domain walls is very large.[2]

The investigated objects were films, condensed in vacuum, of Permalloy (83% Ni, 17% Fe) and of the alloy 79NMA. The film thickness was $h = {\sim}200-600$ Å. The magnetic suspension was a solution (colloidal) of Fe_3O_4 in kerosene, and the stabilizer was oleic acid. The dimension of the MS particles was $L \approx 200$ Å, the suspension density was $\rho = 0.95$ g/cm^2, and the average saturation magnetization was $\bar{J}_s \approx 4$ G.

The experimental procedure is shown schematically in the upper part of Fig. 1. The MS was deposited on part of the film (the shaded region 1 on Fig. 1). The film was then demagnetized with an alternating field with decreasing amplitude H, applied at an angle α to the easy-magnetization axis (EMA). The boundary of the MS was then moved to the right, so that the entire film was completely covered by the MS. The powder figures were observed under an MBI-6 microscope on section 1 of the film, where the MS was present in the demagnetization of the film, and in region 2, where it was absent in this case.

In the lower part of Fig. 1 are shown the powder figures near the boundary (dashed line) between sections 1 and 2. It is seen that the presence of the MS when the film is demagnetized leads to a decrease of the number Δ of the transverse ties per unit length of wall (compare sections 1 and 2). The effect turned out to be strongly dependent on α and on the thickness h of the sample. We present below the values of $\delta = \Delta_2/\Delta_1$ for films of two thicknesses and for angles α from 0 to 70°:

α:	0°	10°	20°	30°	40°	50°	60°	70°
$\delta(h=350$ Å$)$:	1.2	1.5	2.0	2.7	3.6	4.7	4.9	4.9
$\delta(h=600$ Å$)$:	1.2	1.2	1.3	1.3	1.5	1.6	1.6	1.6

Δ_1 and Δ_2 are respectively the numbers of ties per unit length of wall on sections 1 and 2. It follows from the presented values that the greatest influence of the MS on the structure of the walls is observed in thin films and for large angles α. Thus, for $\alpha = 60-70°$ and $h = 350$ Å we observed an almost fivefold decrease of the number of ties when the sample was demagnetized in the presence of the MS.

At larger values of α(80–90°), after the demagnetization of the film, the domains were observed only near the edge of the sample, and no definite conclusion can be drawn concerning the value of α. It follows from this also that when a film is demagnetized in a direction close to the EMA ($\alpha \sim 0°$), $\delta \sim 1.2$ and is practically independent of h.

We note that the walls that are inclined relative to the EMA carry magnetic charges whose polarity alternates from wall to wall.[4] The ties lie asymmetrically on the charged walls.

Figure 2 shows the powder figures on a film of thickness ~200 Oe The left part of the figure is section 1 demagnetized with the MS coating present. Section 2 was demagnetized without the MS. To improve the contrast of the powder figures, a field $H_\perp = 200$ Oe perpendicular to the plane of the layer was turned on (and exerted no influence on the domain configuration). It is seen that in region 1 there were produced dense spirals made up of doubled walls, wound around the film defects (macropores). Similar figures were observed earlier by a powder method on thin Fe–Ni–Mo films,[3] but in the discussion of the results no account was taken

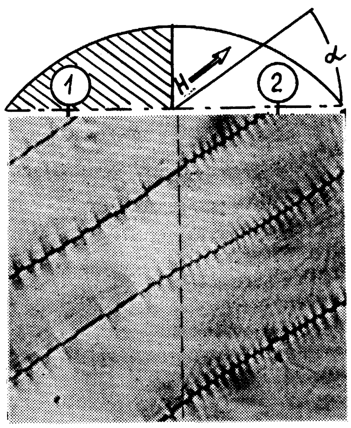

FIG. 1. Diagram of experiment and powder figures on a film 350 Å thick: $\alpha = 60°$. $H_\perp = 150$ Oe, EMA horizontal. Magnification 650×.

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FIG. 2. Powder figures on film of thickness ~200 Å: $\alpha = 50°$ $H_\perp = 200$ Oe, 1—section of film with MS, 2—without MS. Magnification 440×.

of the possible influence of the MS on the domain structure.

In a field oriented in a plane of the film perpendicular to the walls, the density of the powder residue increases over every other wall (the field $H_\perp$ was turned off). This confirms the assumption that the walls are charged. The external magnetic field polarizes the MS particles, and they are attracted to the walls with charge of one sign and repulsed from the neighboring oppositely charged walls. This nature of the effect of the wall polarity in thin films was proved experimentally.[5]

In the presence of MS, the spiral domain structure is quite stable. It vanishes completely only in fields ~300–400 Oe applied parallel to the long axis of the spiral. On the other hand, if the MS is removed from the surface of the film, then the spiral structure is destroyed even without the action of external fields. Spiral structures were not observed by us when the volume concentration of the MS was decreased by three or four times.

On the basis of the described experiments it can be concluded that the formation of tightly wound spirals in the films investigated by us is the result of the direct action of the MS. The mechanism of this action can be described in the following manner. The magnetic suspension becomes condensed near the domain walls, which are sources of considerable stray fields; chains of polarized Fe_3O_4 particles are produced and form a closed sircuit for the magnetic stray flux from the boundaries. The interaction of the MS with the boundaries becomes stronger with increasing linear density of the magnetic charges ($\sim J_s h \sin\alpha$), i.e., with increasing inclination angle of the walls. Furthermore, a particularly important fact in this case, the magnetic suspension, which has a rather high magnetic permeability,[6] exerts a strong influence on the formation of the domain structure and the structure of the domain walls. It is suggested that the MS particle concentration near the walls increases to 30–40 times the average value, and the magnetic permeability reaches values $\mu \sim 10$. The MS shunts, as it were, the stray fields from the walls and makes the walls more stable, since the magnetostatic energy of the system is substantially decreased. The change of the wall energy, in turn, causes a change in the domain structure.

Thus, we have established experimentally in the present study that a magnetic suspension can exert a substantial influence on the structure of the domains and of the domain walls in thin paramagnetic films. This calls for a review of the published data on the domain structures of thin films ($h < 1000$ Å) previously investigated by the powder method. This is particularly important when fields are used at angles $\alpha \gtrsim 50°$ to the EMA. It is not unlikely that the spiral domain configurations observed in Ref. 3 are an instrumental effect of the action of an MS on the domain structure.

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