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ON THE INNER EFFECTIVE FIELD ARISING DURING THE BIDIRECTIONAL ROTATION IN THICK ELECTROLYTICALLY DEPOSITED FILMS

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The paper presents the results of an investigation of the inner effective field during the pulse switching on planar electrolytically deposited permalloy films of micron thickness. The results obtained were compared with those previously obtained on thin films.

I. INTRODUCTION

The investigation of the inner effective field [1—4] arising during the process of the pulse switching of thin ferromagnetic films made it possible to éstimate the previous knowledge of the origin of one of the magnetization reversal mechanisms — of the bidirectional incoherent rotation [5—9] and to arrive at a few new conclusions and assumptions. The correctness of these conclusions regarding the magnetization reversal has been confirmed by direct observation of dynamic domains by means of a straboscopic electron microscope [10]. However, the results obtained up to now refer to thin films, $d \leq 1000$ Å. Further development of the knowledge of the origin of an incoherent rotation of the magnetization vector will be aided by the great interest in the study of the inner effective field in films the thickness of which approaches that of bulk materials and it will make use of comparisons of results obtained on thin films. Electrolytical deposition is the simplest way to prepare films of a thickness of $d = 1.0—3.0$ μm.

II. EXPERIMENTAL TECHNIQUES

Experiments were carried out in thin films electrolytically deposited in a suplhate electrolyte and in a magnetic field with the intensity of 100 Oe [11]. The electrolyte composition and the depositing conditions ensured a film

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composition of 80 % Ni — 20 % Fe. The films were deposited on circular polished copper pads of 20 mm in diameter.

Measurement of the film pulse properties were performed by means of an apparatus described in detail in paper [12]. A two-step pulse technique [1—2] was used for measuring the inner effective field H_e. The field intensity H in the first step was greater than the threshold field of the bidirectional rotation. Papers [1—2] introduce the relation between the field intensity in the second step H_s and the signal voltage measured at the time of the field determining in the second step

$$e_2 = K_1\mathring{M}_{\parallel} = K_2(H_s - H_e), \tag{1}$$

where K_1 and K_2 are coefficients of proportionality, $M_{\parallel}$ the magnetization component in the direction of the easy axis. In our experiments the time for the field determination in the first step was 2.5 ns, in the second 1.2 ns.

From the dependences $e_2(H_s)$ obtained experimentally with different parameters of t_2 the values of the inner effective field H_e were found by extrapolation. The linear dependence gradient $e_2(H_s)$ represents the coefficient K_2 in accordance with relation (1).

The results presented here were obtained on films characterized by the following parameters: a thickness of 2.4 μm, a coercive force of $H_c = 3.7$ Oe, a threshold field of the bidirectional rotation $H_c = 7.8$ Oe, a switching coefficient of $W = 0.33$ Oe μs, an anisotropy field $H_k = 4.8$ Oe.

III. EXPERIMENTAL RESULTS AND THEIR EVALUATION

The effective field dependence on time t_2, obtained at the magnetization reversal field intensity in the first step $H_s = 12.0$ Oe, is illustrated in Fig. 1. The time for the film magnetization reversal in this field is 60 ns. Fig. 1 shows that the inner effective field has a course analogous to that of thin films [2—4], it grows rapidly with time and during the time of $\sim 10^{-8}$ sec attains its maximum value of $H_{emax} = 0.83\ H_s$ and then it gradually drops to some negative value. The fact that the character of the dependence $H_e(t_2)$ is qualitatively similar in thin as well as in thick films can be a proof that the mechanism of the incoherent rotation of the magnetization vector is probably congruent with the magnetization reversal mechanism of thin films up to the thickness of 1000 Å.

As pointed out earlier in papers [1—4], [10], the magnetization reversal is carried out at the initial stage by the process of a rapid rotation of local magnetization vectors which is accompanied with an increase of the magnetization ripple amplitude, with an increase of stray fields and hence also of the inner effective field. This process is finished by the formation of the stripe domain structure. The rotation inside the stripe domain structure is strongly retarded by stray fields and by the effective anisotropy field. These fields influence to a great extent the effective field H_e. At the moment of the retardation of the rotation of the magnetization vector the condition $H_{emax} = H_s$ should be fulfilled. However, due to the film non-homogeneity the retardation of the rotation does not take place simultaneously on the whole surface of the film and thus the instrument recording the signal of the whole sample presents a lower value of $H_{emax} \cong (0.9—0.95)\ H_s$ (for thin layers). After this stage the magnetization reversal process passes into another stage — the main stage which begins with the disintegration of the 180° domain walls. The magnetic charges correspond to the walls and therefore, after their removal, the rotation of the magnetization vectors in the stripe domains becomes useful.

The transition of the magnetization reversal process from the incoherent rotation of the magnetization vector into its main stage is accompanied by the decrease of H_e. The sign change of the inner effective field in the final stage of the magnetization reversal process indicates that it has the direction of the external magnetic field which accelerates this process. This fact can be explained as follows: In the process of disintegration of the stripe domain structure isolated islets are formed in which the magnetization direction is identical with the direction of the total magnetization vector. The diminishing of these islets makes them unstable and therefore their magnetization reversal can be performed by the action of inner fields. It should be taken into consideration that during the final magnetization reversal stage of the rotation of the magnetization vector the direction of the acting effective anisotropy field coincides with the direction of the external magnetic field.

As mentioned above, at a film thickness of 2.4 μm the magnitude of $H_{emax} = 0.83\ H_s$ and in thin films $H_{emax} = (0.9—0.95)\ H_s$. This different behaviour

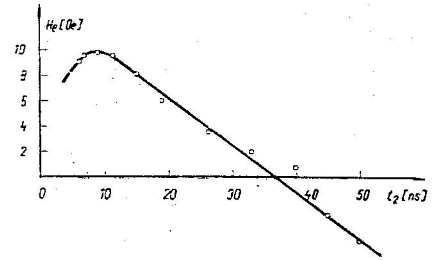

Fig. 1. Dependences of the effective field H_e on time t_2.

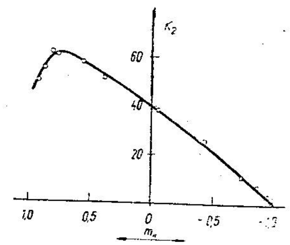

Fig. 2. The course of the change of the coefficient K_2 in dependence on the component $m_{\parallel}$.

of thin and of thick films can be explained by the fact that in thick films a greater effect results from the demagnetization field of the whole film. This action does not consist in a simple adding up to the other inner fields but in the fact that the demagnetization field is not homogeneous along the whole layer. Besides, the films investigated are characterized by a greater local angular stray amplitude and a stray field. Owing to these reasons, the completion of the initial rapid rotation of the magnetization vector, the formation of the stripe domain structure and the transition of the incoherent rotation into the main stage do not take place simultaneously. The method used by us records the mean value of H_e, as a result of which H_{emax} is smaller than H_s.

Another factor proving the applicability of the model introduced for thick films is the character of the coefficient change in equation (1). Fig. 2 shows the dependence of K_2 on the normalized quantity $m_\parallel = M_\parallel/M_s$, where M_s is the magnetization of the saturation, $M_\parallel$ — the magnetization component coinciding with the direction of the easy axis.

In the determination of $m_\parallel$ the initial state is equal to $+1$ and the final to -1. It can be seen that at the beginning K_2 increases with decreasing $m_\parallel$, reaches its maximum value at $m_\parallel = 0.7$ and then drops down regularly to zero. Qualitatively, such a character of dependence of $K_2(m_\parallel)$ corresponds fully to the results presented in paper [13] in which films of a $d = 1000$ Å thickness were studied. In that paper the initial growth of K_2 was explained by the fact that as a result of the initial rapid rotation of the local magnetization vectors, the rotation moment increases and, at the same time, increases the „sensitivity" of the coil winding to the change of the projection component in the direction of the easy axis. The decrease of K_2 can be explained by the transition of the magnetization reversal process into the main stage which is characterized by a considerably greater stray of the direction of the local magnetization vectors.

On the whole, the results of the investigation show that the pulse switching of electrolytically deposited films of micron thickness in the area of the incoherent rotation of the magnetization vector is carried out in a way analogous to that in films of the thickness of $d \leq 1000$ Å. The change in the film thickness in the range investigated has no essential effect on the magnetization reversal mechanism of the incoherent rotation of the magnetization vector.

REFERENCES

[1] Колотов О. С., Погожев В. А., в сб. *Физика магнитных пленок*. Иркутск 1968, 255.
[2] Kolotov O. S., Pogozhev V. A., Telesnin R. V., Phys. stat. sol. *36* (1969), 459.
[3] Kolotov O. S., Pogozhev V. A., Telesnin R. V., Phys. stat. sol. (a)*4* (1971), 57.

[4] Kolotov O. S., Pogozhev V. A., Telesnin R. V., Czech. J. Phys. (to be published).
[5] Телеснин Р. В., Колотов О. С., Физ. тверд. тела *5* (1963), 2654.
[6] Vinogradov O. A., Phys. stat. sol. *15* (1966), 377.
[7] Виноградов О. А., Изв. АН СССР, сер. физ. *30* (1966), 120.
[8] Fuchikami T., J. Sci. Hiroshima Univ. ser. A-II, *30* (1966), 29.
[9] Hagedorn F. B., IEEE Trans on Magn. *4* (1968), 41.
[10] Durasova J. A., Kolotov I. S., Kolotov O. S., Petrov V. I., Spivak G. V., Telesnin R. V., Czech. J. Phys. (to be published).
[11] Veme J., Elektrotechnický čas. SAV *20* (1969), 2.
[12] Колотов О. С., Погожев В. А., Телеснин Р. В., *Методы и аппаратура для исследования испульсных свойств тонких магнитных пленок*. Изд. Московского государственного университета, Москва 1970.
[13] Колотов О. С., Погожев В. А., Физика металлов и металловедение (в печати).

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