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THE INFLUENCE OF A DEMAGNETIZING FIELD ON THE SURFACE MAGNETIZATION PROCESSES OF A SINGLE-CRYSTAL FeSi SPECIMEN

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On a single-crystal rectangular prism-shaped FeSi specimen surface magnetization changes are measured on a surface lying in the crystallographic plane {100} by the magnetooptic method based on the Kerr transversal effect. Measurements were taken at a quasistatic remagnetization of the specimen in the direction of easy magnetization. Changes in the demagnetization effects may be caused by a shortening of the specimen. „Anomalously", surface hysteresis loops are related with the demagnetizing field arising from fictitious surface magnetization charges. The course of this field is calculated for the present case.

I. INTRODUCTION

Magnetooptic methods based on the transversal or the longitudinal Kerr effect are counted among those methods which make it possible to measure surface magnetization changes in iron ferromagnetic specimens. If surface magnetization changes are measured by these methods at a quasi-static remagnetization of the specimen, one may obtain hysteresis loops which in many cases considerably differ from those analogously measured through the volume of the ferromagnetic material [1, 2, 3].

In the present paper the influence of the demagnetizing field on the surface hysteresis loops was studied. Measurements were taken by the magnetooptic method based on the transversal Kerr effect. The experimentally obtained results are related with the demagnetizing field arising because of the discontinuity of the perpendicular component of the surface magnetization.

II. EXPERIMENTAL RESULTS

Surface magnetization processes were observed on a carefully prepared rectangular p ism-shaped single-c ystal FeSi specimen (Si content 3.2 wt $\mathscr{S}$)

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of a 1.72×2.7×17.4 mm dimension, with the faces of the specimen in the crystallographic planes {100}. The magnetooptic measurements of the surface magnetization changes were taken on one surface of the specimen (2.7× ×17.4 mm) in little planes of 2.7×2 mm dimensions, which lay at different distances from the centre of the rectangular prism (at distances of 0, 3, 5, 7 mm from the centre of the specimen). Changes in the demagnetization effects were obtained by a successive shortening of the specimen on both sides (from the original length of 17.4 mm) to 13.9, then to 11.3 and to 7.7 mm, while measurements on the remaining little planes were repeated. To eliminate the possible influence of state alterations of the measured surfaces, the latter were left intact during all the measurements.

In Fig. 1 surface hysteresis loops are shown. They were always measured in the same little plane at a distance of 3 mm from the centre of the specimen, while the latter was of different lengths (17.4; 13.9; 11.3; and 7.7 mm). A considerable influence of the changes of the demagnetization effects is shown in the figures.

In the specimen of an original by 17.4 mm length volume hysteresis loops were measured by the ballistic method, using a narrow sensing coil. The distances from the centre of the specimen were 0, 3, 5, and 7 mm. The results of the measurment are given in Fig. 2. The value of the coercive force of the specimen was $H_c = 0.03$ Oe and so the area of the hysteresis loop is lying in the thickness of the line. To make comparison possible, in Fig. 3*a*, *b*, *c*, *d* the relative values of the volume magnetization dependent on the position of the sensing coil from the centre of the specimen are shown. They are valid for fields of 1200, 500, 300, 0 Oe (curve 1). There are also to be found the relative values of the surface magnetization appertaining to these fields and places measured by the magnetooptic method at a decline of the external magnetic field (curve 2).

Before measuring, the domain structure was observed on the specimen surface by the powder-pattern method to check the exactness of the surface orientation. These observations proved that the mentioned surface lay in the crystallographic plane {100} within an accuracy of $\pm 0.5°$.

III. CALCULATION OF THE DEMAGNETIZING FIELDS

In the first approximation we assume that the specimen of a $2a \times 2b \times d$ dimension will be homogeneously magnetized in its whole volume through magnetization by a homogeneous magnetic field of an axial direction (Fig. 4). In this way fictitious surface magnetic charges (if a discontinuity of magnetization was marked by fictitious magnetic charges) will arise only on the surface $(x, y, 0)$ and (x, y, d) and the density of their area σ will be constant. Under

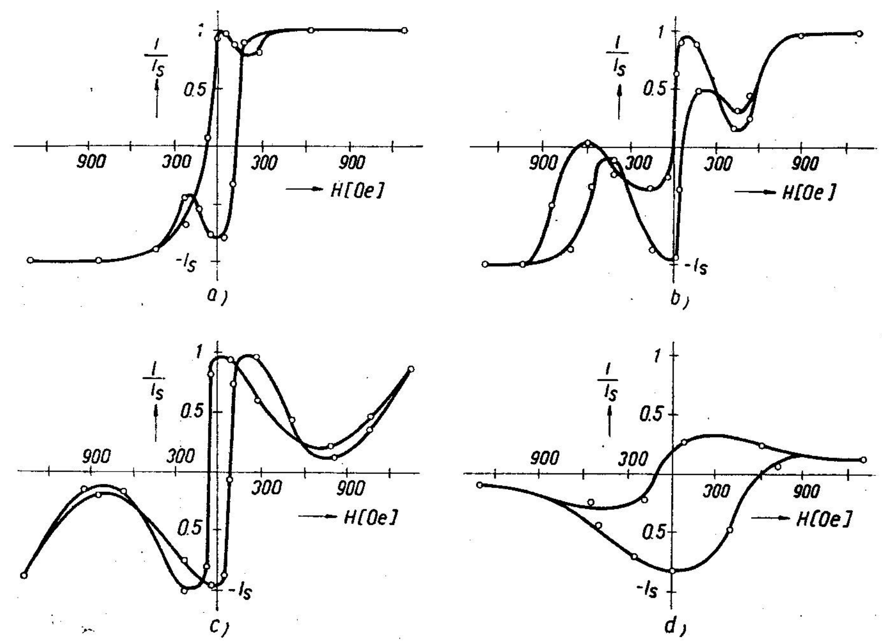

Fig. 1. Surface hysteresis loops measured by the magnetooptic method at distances of 3 mm from the centre of the specimen at different lengths of the latter: *a*) 17.4 mm' *b*) 13.9 mm; *c*) 11.3 mm; *d*) 7.7 mm.

these conditions a demagnetizing field arises, with H_x, H_y, H_z components, which were by application of [6] calculated along the rectangular prism axis $(0, 0, z)$, along the rectangular prism fase axis $(a, 0, z)$ and along the rectangular prism edge (a, b, z), with $0 < z < d$.

The components of the demagnetizing field along the rectangular prism axis are as follows:

$$H_{xA} = H_{YA} = 0$$

$$H_{zA} = -4\sigma\{\arcsin \frac{ab}{[(a^2 + z^2)(b^2 + z^2)]^{1/2}} + \arcsin \frac{ab}{\{[a^2 + (d - z)^2][b^2 + (d - z)^2]\}^{1/2}}:$$

along the rectangular prism face axis

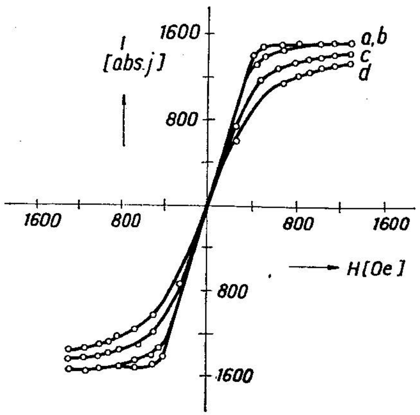

Fig. 2. Volume hysteresis loops measured at different distances from the centre of the specimen: *a*) 0 mm, *b*) 3 mm; *c*) 5 mm; *d*) 7 mm.

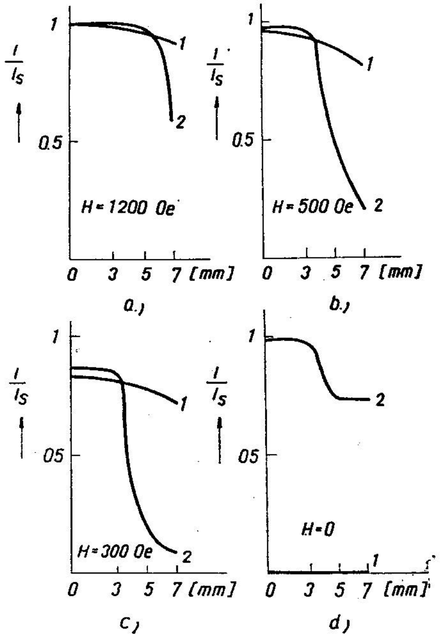

Fig. 3. Relative values of volume and surface magnetization dependent on distances from the centre of the specimen at different fields.

$$H_{xB} = 2\sigma \left\{ \ln \frac{[4a^2 + z^2]^{1/2}}{z} \frac{[b^2 + z^2]^{1/2} + b}{[4a^2 + b^2 + z^2]^{1/2} + b} - \right.$$

$$\left. - \ln \frac{[4a^2 + (d-z)^2]^{1/2}}{d-z} \frac{[b^2 + (d-z)^2]^{1/2} + b}{[4a^2 + b^2 + (d-z)^2]^{1/2} + b} \right\},$$

$$H_{yB} = 0$$

$$H_{zB} = -2\sigma \left\{ \arcsin \frac{2ab}{[(4a^2 + z^2)(b^2 + z^2)]^{1/2}} + \right.$$

$$\left. + \arcsin \frac{2ab}{[4a^2 + (d-z)^2][b^2 + (d-z)^2]\}^{1/2}} \right\}.$$

The components of the demagnetizing field along the rectangular prism edge H_{xC}, H_{yC}, H_{zC} were calculated similarly.

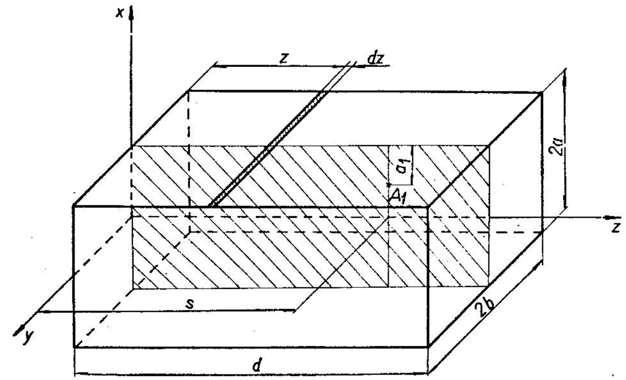

Fig. 4. Model of the specimen.

The given components for our specimen ($2a = 1.72$ mm; $2b = 2.7$ mm; $d = 17.4$ mm) were calculated by the computer MINSK 22. Results for the surface density equal to 1 are given in Fig. 5*a*, *b*. In Fig. 5*a* the course of the longitudinal components of the demagnetizing field H_{zA}, H_{zB}, H_{zC} is shown. The components are antiparallel to the external magnetic field. In Fig. 5*b* the course of the H_{xB} and H_{xC} components on the surface $(-a, y, z)$ is shown. These components are perpendicular to the direction of the external field. The idea of a homogeneously magnetized specimen is disturbed by the existence of these transversal fields. But we shall assume henceforward that the density of the fictitious magnetic charges on the surfaces of the specimen $(x, y, 0)$ and (x, y, d) is constant. Since the transversal fields H_{xB} exist, the magnetic charges will appear on the surface $(\pm a, y, z)$. The density of the former equals the intensity of the H_{xB} field which is assumed to be the function of the coordinate z only (i.e. $H_{xB} = H_{xC}$). If the magnetic charges are distributed in this way, an additional field arises, the component of which, directed towards the external field in point A_1 $(a - a_1, 0, s)$ (Fig. 4), will be

$$H_{zD} = 2b \int_0^d KH_{xB}(z) \frac{(z-s)\,dz}{[a_1^2 + (s-z)^2][a_1^2 + b^2 + (s-z)^2]^{1/2}}.$$

Along the rectangular prism face axis $(a, 0, z)$ this field (for $\varepsilon \leqslant z \leqslant d - \varepsilon$, when $\varepsilon = 0.1$ mm) has a course shown in Fig. 5*c*. In the transversal direction for $s = 1.7$ mm and for the numerical value $K = 1$ its course (for $\delta \leqslant a_1 \leqslant 2a - \delta$, when $\delta = 0.001$ mm) is shown in Fig. 5*d*, curve 1. Curve 2 in Fig. 5*d* shows an analogous course of the z-component of the field across

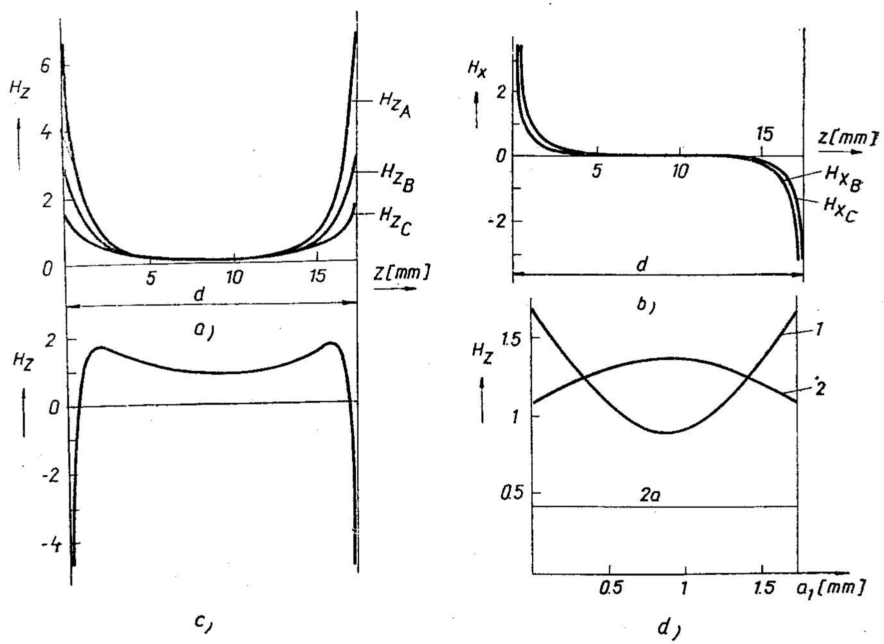

Fig. 5. Courses of the demagnetizing field components obtained by calculation.

the specimen from charges placed on the faces of the specimen. Due to the charges at the end of the specimen, the z-component of the field is lower on the surfaces ($\pm a, y, z$) than in the axis of the specimen and on the contrary it is higher than in the axis due to charges on the surfaces ($\pm a, y, z$). The resultant field, obtained by a total of both fields, may show a higher or lower value on the surfaces ($\pm a, y, z$) than that in the axis of the specimen accordin to the relative charge density at the ends and on the surfaces ($\pm a, y, z$).

IV. ANALYSIS OF THE OBTAINED RESULTS

Analysing the experimental results we start from hypotheses similar to those in Neel's phase theory [7]. We assume that the given specimen as regards its magnetic properties approaches an ideal one in which mainly reversible magnetization processes take place and the Bloch wall displacements are realized at a zero effective field (it is a question of magnetizing the single crystal specimen in the direction of at easy magnetization). In our case this assumption is sufficiently fulfilled with respect to the very low value of the

coercive force of the material and to the negligible area of the hysteresis loop. Further we start from the fact that magnetization at any point is determined by the resulting magnetic field present at this point (we have in mind a medium magnetization calculated for sufficiently small surroundings of that point). Thus the magnetooptically measured surface magnetization will be of that value in the direction of magnetization which corresponds to the component of the effective field in this direction. It is necessary to mention in this place that according to a method based on the Kerr transversal effect only that component is of use which is perpendicularly directed to the plane of the descending linearly polarized light and a medium magnetization of the illuminated little plane is measured. As the external field and the specimen placed in it are perpendicularly orientated to the plane of the descending light ray, during the magnetooptic measurements only the surface magnetization changes of the external field direction will be applied. Further we assume that there are no volume magnetic charges in the specimen or that they are distributed at a density which does not cause any substantial alterations in the course of the demagnetizing fields calculated from the surface charges of the specimen.

On the basis of these assumptions, the "anomalous" course of the surface hysteresis loops measured by the magnetooptic method may be described as follows:

In higher fields, in which the specimen is practically magnetized up to saturation there are no fictitious magnetic charges on the surfaces ($\pm a, y, z$) (except the areas close to the ends of the specimen) and therefore the demagnetizing field on the specimen surface will be lower than the average one in the cross—section of the specimen (according to the course calculated and shown in Fig. 5*d*, curve 2). Thus surface magnetization reaches the value of the saturation magnetization (Fig. 1*a*, *b*). By a decrease of the external field the fictitious magnetic charges appear also on the surfaces ($\pm a, y, z$) and they influence the longitudinal demagnetizing field in such a way that an increase of the surface demagnetizing field with regard to the average demagnetizing field calculated for the given cross-section of the specimen can be observed (an increase of the contribution of the demagnetizing field from the charges on the surfaces ($\pm a, y, z$) is shown in Fig. 5*d*, curve 1). Consequently, the component of the measured surface magnetization is decreasing (Fig. 1*a*, *b*, *c*).

At a further decrease of the external field (in surroundings of the zero effective field), the average volume magnetization reaches remanence, but we may admit that the real course of the small external fields will not differ greatly from the mentioned one. In consequence of such a distribution of magnetization no magnetic charges arise on the surfaces ($\pm a, y, z$). Thus the demagnetization field arises only from the charges on the faces of the specimen and its value on the surfaces ($\pm a, y, z$) is lower than the average value in the cross-section of the specimen (curve 2, Fig. 5*d*). In this way the surface effective field will be orientated in the direction of the external field, which will cause an increase of the measured component of the surface magnetization. (Fig. 1*a*, *b*, *c*).

In the given cases we are dealing with very small alterations of local demagnetizing fields which are of the coercive force order, i.e. hundredths of Oe. In spite of a low coercive force, the surface magnetization changes cannot have a revesible course (as shown in Fig. 1*a*, *b*, *c*, *d*) and that is why the value of surface magnetization in the given effective field will depend on the state at which the changes were realized.

In our case thei nfluence of the demagnetizing field on the surface magnetization processes may be described like that in the extreme case of a long specimen (when the demagnetizing effects may be neglected), the magnetization changes will have the same course on the surface as in the volume of the specimen. Formation of the demagnetizing field and especially its non-homogeneity due to the prism-like shape of the specimen cause that the surface magnetization processes considerably differ from the analogously measured magnetization changes in the volume of the specimen. From the experimental results given in Fig. 1 it follows that the influence of the demagnetization effects on the surface magnetization processes is a considerably large one.

Near the ends of the specimen a considerable influence of the demagnetization effects on the value of the longitudinal component of the surface magnetization can be observed. The magnetization shows a rapid decrease in the area of the external fields (cf. Fig. 3*a*, *b*, *c*, *d*). To achieve saturation magnetization also at the ends of the specimen one should apply much higher fields than it was possible in our arrangement. Similarly, when the specimen is short with respect to the cross-section, as in our case, when the specimen was shortened to 7.7 mm, the surface magnetization shows a decrease in the increasing field of 1000 Oe (Fig. 1*d*). The course of the magnetization is evidently assymmetrical in this figure. It was not the aim of this paper to explain the reason.

V. CONCLUSION

The paper reports about the experimental results obtained by measuring the surface magnetization changes in a single-crystal rectangular prism-shaped specimen at its quasistatic remagnetization in the direction of easy magnetization. The influence of the demagnetization effects of the specimen on the surface magnetization processes is studied. "Anomalous" courses of the surface hysteresis loops are related with the demagnetizing fields arising from the fictitious surface magnetic charges.

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