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Inductive observation of transitions from [100] magnetic domains to [010] and [001] in silicon-iron

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Transitions of the magnetization from the [100] to [010] and [001] directions were observed by inductive methods. Enhancement of the signals was obtained by a crossed excitation-signal windings arrangement. The results are interpreted in terms of the internal [010], [001] domains.

INTRODUCTION

The magnetization of silicon-iron when occurring at an angle to the easy axis is known to be very complex. Some authors have studied the problem, suggesting models for the resulting magnetic structures. These studies are based mainly on data gathered through nondirect methods of observation for the magnetization, e.g., surface domain structures, magnetostriction, and Mössbauer spectroscopy. This work intends to show the possibility of observing, by inductive methods, some magnetic transitions relevant for the study of the subject. In particular we interpret some results in terms of population and depopulation of [010] and [001] domains (*c* type according to the nomenclature of Zaykova *et al.*[1]). There are also suggested ways to obtain quantitative relations among the parameters involved.

EXPERIMENT

The experiments were made on sheets of Goss texture silicon-iron (texture {110}⟨100⟩) with an arrangement of excitation and signal pickup coils as shown in Fig. 1. In the same figure are shown the shape, dimensions, and the angular relations for the parameters. The angle between windings enhances the desired signals against the background of the main flux. The samples were made by stacking 16 of such sheets in order to increase the signal, to allow for the application of compressive stress, and to obtain a reliable average response of the grains. The cuts were made by spark erosion. Sixteen different constructional angles θ were chosen, but as we can exchange primary and secondary windings we got effectively 31 samples characterized by angles θ between 85° and $-85°$. We define θ as positive when the easy magnetization axis (ema) is clockwise with respect to the H axis. The windings consisted of 40 turns each. The output signals were measured and also registered photographically from an oscilloscope. The excitation was obtained from a sinusoidal current source at 65 Hz.

RESULTS

In Fig. 2 are shown some typical signals together with an excitation current curve for reference. The total signal can be described as a smooth contribution from the main flux plus an additional contribution with a more complex character (secondary peaks) as shown in Fig. 2(e). This structure is modified by mechanical stresses, the applied field H, and angle θ, in this way allowing verification of the effects of each of these parameters. Comparing Figs. 2(b) and 2(c), corresponding to samples with $\theta = -70°$ and $\theta = 85°$ both excited at 90 mA, it is possible to verify the effect of stress σ on the secondary peaks (sp) amplitudes. It can be observed that the sp amplitudes increase with applied stress σ for samples with $\theta = -70°$, and conversely they decrease when $\theta = +85°$. The increase in amplitude of the sp with negative polarity may reach a point where the total signal has its phase reversed. This kind of behavior is verified for the whole family of samples characterized by positive and negative angles θ, respectively. It can be also observed that an increase in the field H has as an effect the increasing of the relative amplitude of peak A.

DISCUSSION

To interpret the experimental results we consider the magnetization mechanisms for a direction noncollinear with the ema. We know that basically motions of 180° walls occur between $\pm$[100] domains and 90° wall motions between them and the [010] and [001] ones. Only in the latter stages of magnetization will the rotation processes occur. By convenience, we start the analysis of the domain behavior from a saturated situation, when the excitation begins to decrease. When the rotation stage is finished, the three types of do-

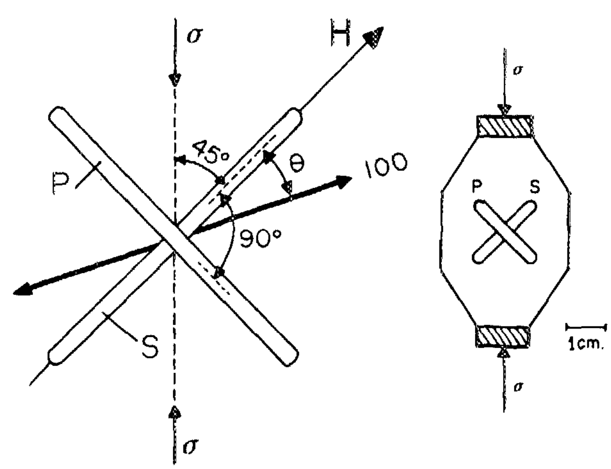

FIG. 1. Relations among the directions of the excitation and signal coils, the direction of stress σ, and the [100] easy magnetization axis. P and S indicate the excitation and signal coils.

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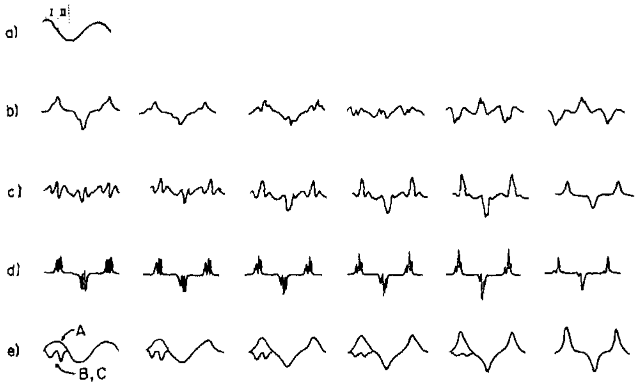

FIG. 2. (a) Excitation current. (b) Output signal for sample $\theta = -70°$, excitation current $I = 90$ mA (peak value). (c) Output signal for $\theta = 85°$, $I = 90$ mA. (d) Output signal for $\theta = 85°$, $I = 300$ mA. In (b), (c), and (d) the stress σ increases from left to right, going from 0 to 10 N/nm^2. (e) Decomposition of the signal in (c).

mains may coexist in the sample. The [100] domains will depopulate going to $-[100]$ [transition 1, Fig. 3(a)]. The out-of-plane domains [010] and [001] will decay to $\pm[100]$ [transitions 2 and 3, Fig. 3(a)]. For zero field the $\pm[100]$ will be the only ones to persist. When the excitation passes through zero and then increases in the opposite direction, transitions 1, 2, and 3 will occur as shown in Fig. 3(b). As can

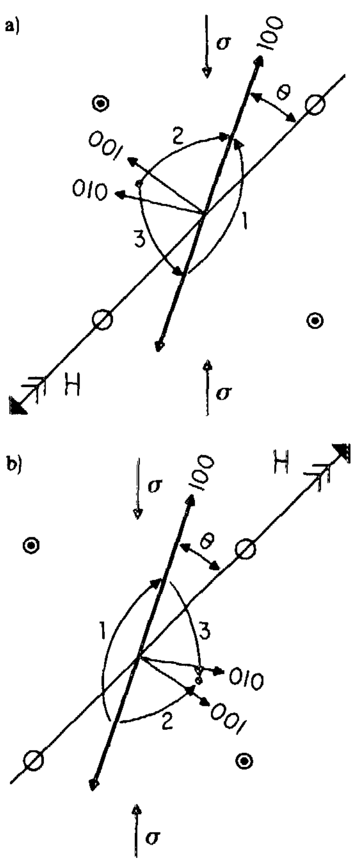

FIG. 3. Schematical representation of the transitions occurring in samples characterized by a negative angle θ. (a) and (b) correspond, respectively, to regions I and II in Fig. 2(a).

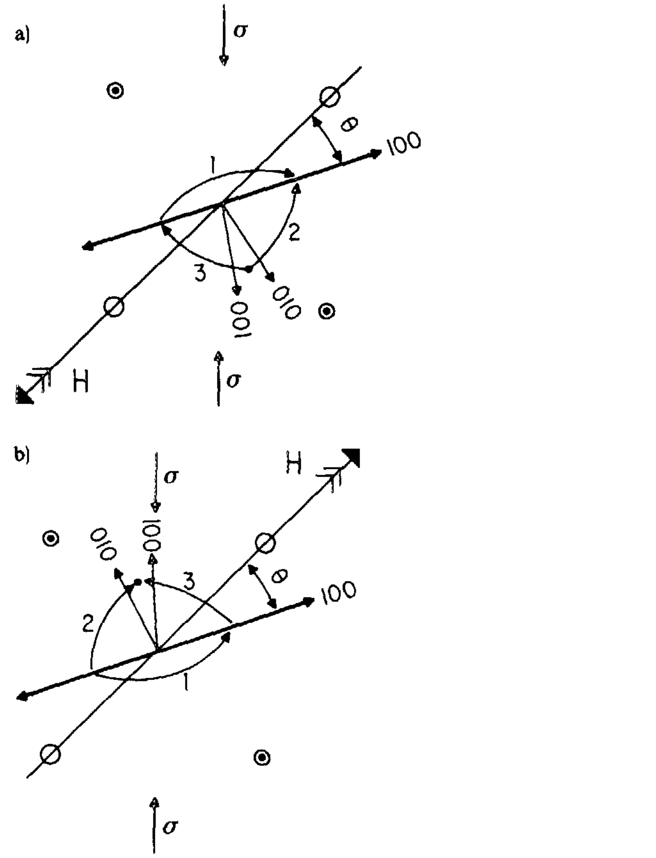

FIG. 4. Schematical representation of the magnetic transitions occurring in samples characterized by a positive angle θ. (a) and (b) correspond, respectively, to regions I and II in Fig. 2(a).

be seen by Fig. 3, due to the relative orientations of the windings and ema, transition 3 gives a contribution to the signal that is opposite to that given by 1, contrasting against it. Transition 2, being smaller and in the same sense, becomes smeared in the contribution of the main flux. We assign to the transitions of type 1 the origin of peaks A, and to transitions 3 in Figs. 3(a) and 3(b) the origin of peaks B and C. The situations shown in Figs. 3(a) and 3(b) correspond to regions I and II in Fig. 2. The effects of mechanical stress σ corroborate this interpretation. In silicon-iron a compression initially reduces the permeability along its axis of application and increases the permeability in its normal plane. In the case of negative angles θ, the [010] and [001] domains will be favored by stress σ. This effect can be verified in Fig. 2(b) that shows peaks B and C increasing with σ, indicating that increasing volumes are involved in transition 3. For the samples characterized by a positive angle θ the situation is similar, the details being given by Figs. 4(a) and 4(b). There is a peculiarity about the effect of the stress σ; the $\pm[100]$ domains are now the favored ones, tending the [010] and [001] domains to be extinguished. This effect can be seen in Figs. 2(c) and 2(d) where it is verified that peaks B and C decrease with stress σ. Comparing Figs. 2(c) and 2(d) that show the behavior of the sample $\theta = 85°$ with two levels of excitation, we can verify the effect of the applied field H that favors the $\pm[100]$ domains. This effect appears as a decrease in relative magni-

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tude of peaks B and C and can indicate a greater contribution of domain rotation mechanism. A comparison between the effects of H and σ can give an estimate for the ratio of the parameters involved. A work is in progress with this aim. In our opinion the kind of transitions we have dealed with can explain the signal anomalies noticed earlier in the literature.[2,3]

ACKNOWLEDGMENT

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