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X-RAY TOPOGRAPHIC INVESTIGATION OF FERROMAGNETIC DOMAIN STRUCTURES WITH CLOSURE DOMAIN CONFIGURATIONS IN IRON-SILICON SINGLE CRYSTALS

M. SCHLENKER
Laboratoire d'Electrostatique et de Physique du Métal du C. N. R. S., Cedex 166, 38 Grenoble-Gare

M. KLEMAN
Service de Physique des Solides (*), Faculté des Sciences, 91, Orsay

Résumé. — On a étudié la structure en domaines de plaques monocristallines de fer-silicium (2.4 % en masse), de surface (110), soumises à une traction parallèle à [110] à l'aide de l'effet Kerr et de la méthode de topographie en rayons X par transmission de Lang. L'usage de sections et de topographies par translation renseigne sur les distorsions du réseau, et donc sur la structure des domaines à l'intérieur d'échantillons d'épaisseur voisine de 0,1 mm. En particulier, certaines sections semblent fournir des images de parois à 90° internes, et les franges qui apparaissent sur les topographies peuvent s'interpréter comme des lignes de niveau sur des parois internes.

Abstract. — The domain structure of single-crystal (110) plates of 2.4 wt % silicon-iron was investigated under tensile stress parallel to [110] by means of the Kerr technique and of Lang's method of transmission X-ray topography. It was possible, by using both section and traverse topographs, to gain information about the lattice distortions, and therefore the domain structure, within specimens about 0.1 mm thick. In particular, some section topographs seem to provide images of internal 90° walls, and the fringe system which appears on traverse topographs can be interpreted as a set of equal-depth contours for internal walls.

I. Introduction. — X-ray topographic techniques, and in particular Lang’s method [1], have now gained, primarily through Polcarova's work [2-6], a place of their own as methods for observing ferromagnetic domain structures.

It is well known that the contrast of crystal defects such as dislocations can be interpreted within the framework of the dynamical theory of X-ray diffraction in nearly perfect crystals (reviewed in [7] and [8]); it arises from the effect of slight local departures from perfect crystal periodicity on the propagation of wave-fields [9]. It was generally assumed from the beginning, and also proved experimentally [10], that the contrast of ferromagnetic domain walls has the same origin. Because of magnetostriction, the crystal suffers a distortion related to the direction of the magnetization, $\mathbf{M}$ and $-\mathbf{M}$ being equivalent in this respect. Thus 180° walls are not visible. In particularly simple domain structures, the black or white contrast of 90° walls in iron-silicon could thus be associated with the sign of the difference in distortion of the neighboring domains [11] and interpreted in terms of the dynamical theory of X-ray diffraction by invoking effects of total reflection and refraction of wavefields at the boundary [12].

One of the great assets of this method is that it should make it possible to probe the domain structure within comparatively thick samples, when only surface domain configurations can be studied by conventional methods. In an attempt to take advantage of this asset, we investigated situations where the domain structure involves simple closure configurations, induced either by a magnetic field or by elastic stress.

II. Experimental results. — 1. EXPERIMENTAL METHOD. — We shall discuss the results concerning domain structures induced by elastic stress in (110) plates of single-crystal Fe-Si (2.4 wt %) grown by the Bridgman method. The plates were cut into squares 12 $\times$ 12 mm$^2$, 100 to 150 $\mu$ thick, with sides parallel to [001] and [110]. A tensile force could be applied along [110] by means of a jig designed to enable observation of the stressed specimen either on the Lang camera or by means of a Kerr magneto-optical device for surface-domain examination.

The application of stress led to the appearance of a pattern of surface domains elongated along [110] but magnetized along $\pm [001]$, the well-known « pattern I » investigated by Dijkstra and Martius [13].

2. METASTABILITY OF THE STRESS-INDUCED DOMAIN STRUCTURE WHEN THE STRESS IS REMOVED. — A striking feature of this pattern is that, when the stress is relieved, the domain structure remains unaltered; it is then in a metastable state, as a slight disturbance such as vibration or a magnetic field causes it to vanish into the familiar structure of bands parallel to [001]. The traverse and section topographs obtained from this domain structure with and without external stress were found identical (see, e.g., Fig. b and c).

3. GENERAL FEATURES OF THE TOPOGRAPHS. — a) A comparison of figure a and b shows that the period of the X-ray images corresponds to half the period of the surface domain structure.

b) Topographs made with the same MoK$_a$ radiation, but with either 110 (Fig. b or c) or 220 (Fig. e) reflections, look very different; we showed that the dark line in the 220 topographs is shifted by one-half of a surface-domain width with respect to the sharp black fringe of the 110 topographs.

(*) Laboratoire associé au CNRS.
a) Surface domains, Kerr effect, state I; b) Mo Ka₁ 110 traverse topograph (T. T.) of same region, same state as in a; c) Mo Ka₁ 110 T. T., state II; d) Co Kα₁ 110 T. T., state I; e) Mo Ka₁ 220 T. T., state I; f) Mo Ka₁ 110 section topograph (S. T.), state II; g) Co Kα₁ 110 S. T., state I; h) Mo Ka₁ 220 S. T., state I; i) cross-section along (110) according to model of [13].

State I = metastable condition, no external stress applied. State II = with tensile stress \( \sim 8 \times 10^8 \) dyn cm\(^{-2} \) applied along [110]. The mark next to each photograph corresponds to 100 \( \mu \)m.

3. The variety in aspect of the various topographs shown, which are all made using the same family of (110) planes as reflecting planes, is certainly connected to the different values of two essential parameters of the dynamical theory of X-ray diffraction: the Pendellösung period \( \Lambda \) and the angular width \( \delta \) of the intrinsic rocking-curve, which is a measure of the sensitivity of the reflection used to crystal distortion. The values are respectively:

\[
\begin{align*}
\Lambda &= 9.7 \mu \text{rad} = 4.2 \times 10^{-5} \text{rad for MoKα₁ 110} \\
\Lambda &= 14.8 \mu \text{rad} = 1.4 \times 10^{-5} \text{rad for MoKα₂ 220} \\
\Lambda &= 3.5 \mu \text{rad} = 1.1 \times 10^{-5} \text{rad for CoKα₁ 110} \\
\end{align*}
\]

4. The difference in distortion on crossing a (111) wall between a closure domain magnetized along [001] and a main domain magnetized along [100] or [010] causes the characteristic parameter of a wave-field, the departure from Bragg's angle \( \Delta \theta \), to change by \( \pm 0.75 \Delta \theta \approx 2 \times 10^{-5} \text{rad} \). This value was calculated using the results of [11], i.e. assuming the wall to be infinite and isolated; it is smaller than \( \delta \) for Co 110 and Mo 110 reflections, but larger than \( \delta \) for the Mo 220 reflection. This means that, in the Mo 220 case, the wave-fields will suffer large deviations on crossing the (111)-90° boundaries.

5. The fringe periods observed on 110 traverse topographs taken with AgKα₁, MoKα₁ and CoKα₁ radiation are proportional to the corresponding Pendellösung periods. It is well known that one fault-plane [14] or twin-lamella [15] inclined with respect to the surface induces on traverse topographs equal-depth fringes with a depth-interval equal to \( \Lambda \). The spacing observed here is consistent with the angle of about 35° between a { 111 } \( \sim \) 90° wall and the surface which is assumed in Dijkstra and Martius' model.

6. The striking feature of the Mo 220 section topograph (Fig. h) is that it looks like the expected cross-sectional view (Fig. f). However, we must emphasize: a) that, under the conditions of high absorption used (\( \mu d \sim 4 \)), the contribution of « direct images » — the only ones for which a kinship to the cross-section can be claimed — is very slight. Therefore, although it is likely that the images which look like the closure-domain walls actually do originate from them, care should be taken in their analysis;

b) that the horizontal V-shaped streak can not be thought of as the image of the wall between main domains, which must be parallel to (001). It is probably related to the complex distribution of distortions which prevails at the intersection of the three walls.

The situation there bears resemblance to a twin tip; the corresponding stress could be partly relaxed by a complex magnetization configuration, which has not yet been calculated. A thorough understanding of the contrast may yield some information about the nature of the wall intersections.
References

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