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Dislocation Images in Pure Iron Observed by Transmission Electron Microscopy

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The dislocation image has line or dotted features, which depends essentially upon the reflecting condition. Line images: 1) The dislocation image produced by a single reflection is usually formed of a single line, sometimes, of double lines. 2) Even when it is due to multiple reflections, the image sometimes looks like a single line. 3) The image having black contrast is generally accompanied by white side-lines, and when the latter predominate, the image is observed as a white dislocation image. Dotted images: 1) Each dot in the dotted images is frequently composed of the white and the black regions lying side by side distributed alternately along the dislocation line. 2) The zig-zag image is considered as a special feature of the dotted image. 3) Complex features of the dotted image are due to multiple reflections. Finally, it is shown that the foil is bent by the dislocation for relief of the dislocation stress.

A kinematical theory of the contrast of dislocation images has recently been proposed by Hirsch *et al*[1] (1960), and explained a number of basic features of the observed images. The theory does not, however, explain more complex ones. To study the characteristics of the dislocation, unambiguous interpretation for all kinds of the images is needed, for which more definite knowledge concerning the relation between dislocation image and reflecting condition must be available. The present work has been carried out to obtain such data in the case of pure iron, using electro-polished beaten foils.

The dislocation image has line or dotted features, depending upon the reflecting condition. This dependence has been clarified by the dark field image method and also by small variation of the incident angle of electron beam, as follows:

Line Images of Dislocations: 1) Generally the contrast of dislocation image near an extinction contour is mainly due to the reflection of the same index as that of the contour. The image becomes weaker and narrower with the distance from the extinction contour, i. e., with the deviation angle from the Bragg condition (see Fig. 1).

2) When the image contrast is produced by a single reflection, the image is usually observed as a single line, as seen in Fig. 1. (a) is the bright field image and (b) is the dark field image of (121). Comparing these two photographs, it is found that the black contrast of the dislocation image in the former is due to (121) reflection, and that on both sides of this images there are white regions (↑) which mean strong transmission of the electron

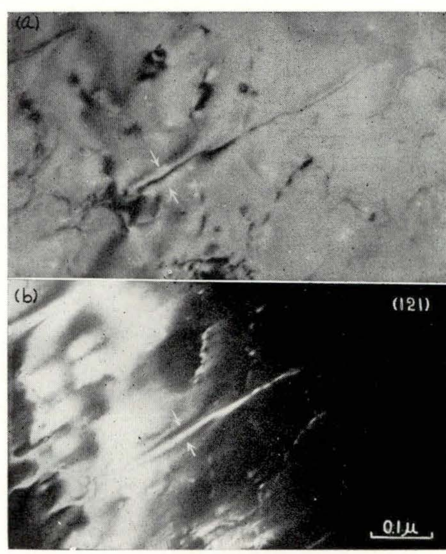

Fig. 1. Single image of dislocation produced by one reflection.

Fig. 2. Triple images of dislocations.

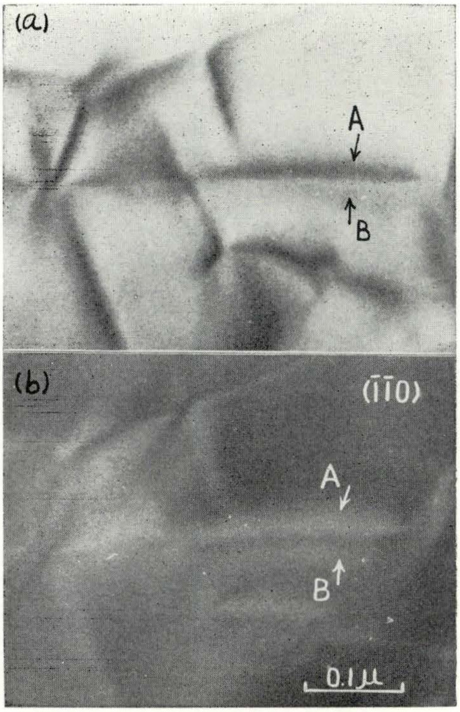

Fig. 3. Double image produced by a single reflection.

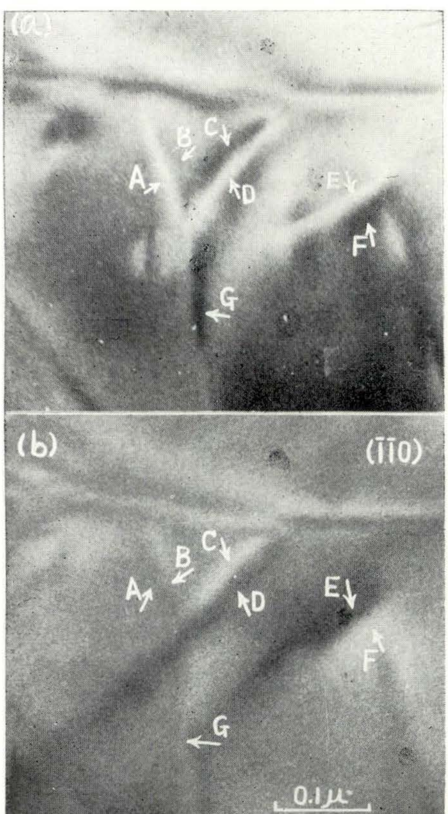

Fig. 4. White dislocation images. Each letter indicates the corresponding portion.

beam. This kind of image sometimes appears as a triple image, which is accompanied by broad side-lines, as seen in Fig. 2. It can not always be said that the dislocation image appears as a single line when one reflection occurs, (see Fig. 3).

3) In Fig. 4 the dislocation images are observed as white lines, i.e., so called white

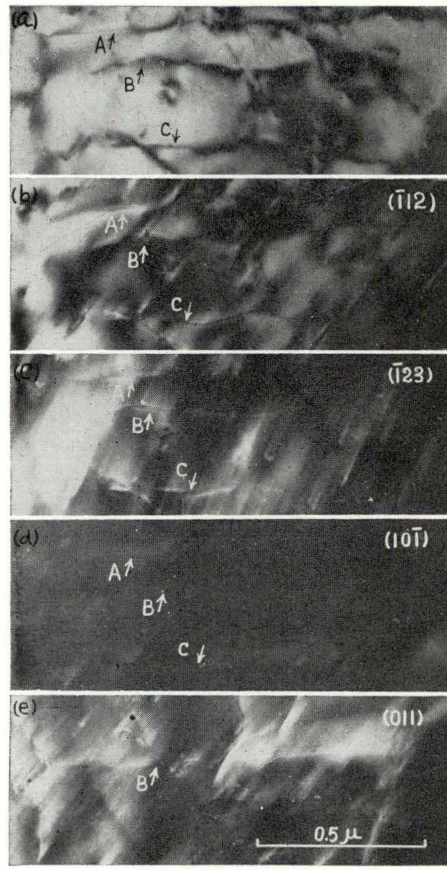

Fig. 5. Single image produced by multiple reflections.

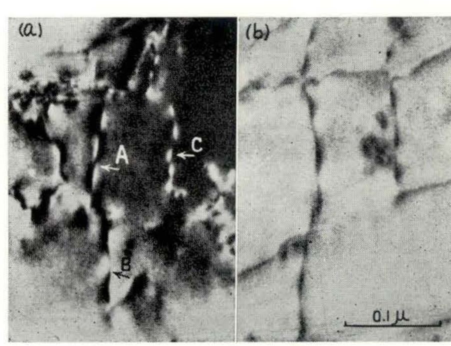

Fig. 6. Dotted images of dislocations.

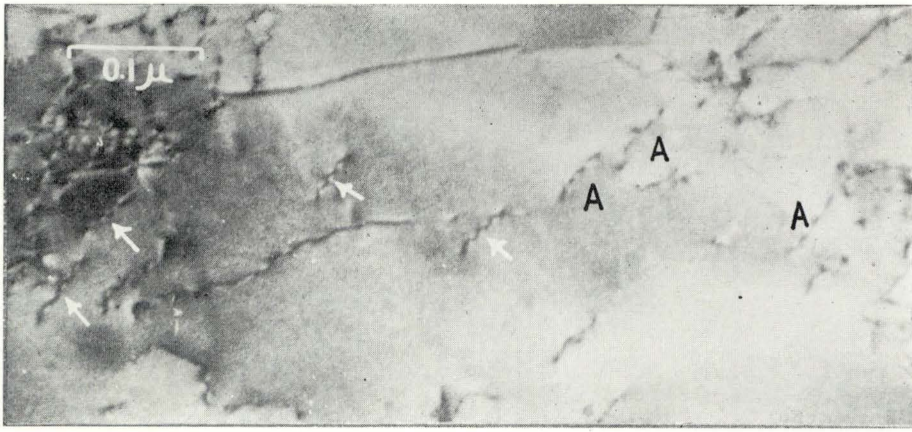

Fig. 7. Zig-zag images of dislocations.

dislocation images, as found by Hirsch *et al*[1). In the dark field image (b) those portions have black contrast accompanied by side-lines of white contrast. It is therefore reasonable to conclude that the white dislocation image is an extreme case of the dislocation image accompanied by the white side-line; i.e., in this case the contrast of the white side-line is strong as compared with that of the black dislocation image.

4) Sometimes the image looks like a single line even when it is due to multiple reflections. Fig. 5 is a typical example of such a case, in which each dislocation image is rather broad. Comparing Fig. 5 (a) with its dark field images of $\bar{1}12$, $\bar{1}23$, $10\bar{1}$ and 011, the following facts are found: Images A and C are due to three reflections, and image B is indeed due to four reflections. Furthermore, it is especially interesting that in Fig. 5 (b) each dislocation appears as a double image separated with a narrow and sharp black line which is observed as white in other reflections.

Dotted Images of Dislocations: 1) Each dot in the dotted images is frequently composed of the white and the black regions lying side by side, and distributed alternately along the dislocation line, as seen in Fig. 6. In the image of this type, the boundary between these two regions is considerably sharp and is on a line throughout the dislocation concerned, and thus the white regions are observed as dots in a zig-zag row, as seen at image C. It should be also noted that the black contrast of one side of the dotted image becomes so faint with the distance from the dark matrix in the photograph that only part of the boundary is visible, as seen at image B. And finally it takes a feature shown in Fig. 6(b).

2) The zig-zag image is considered as a special case of the dotted image. Comparing various images in Fig. 7, it is noted that the zig-zag image (↑) changes to the dotted one signed by A with the distance from the dark region of the matrix, i.e., this kind of image also depends on the reflecting condition. The zig-zag image is occasionally produced by two reflections, as seen in Fig. 8.

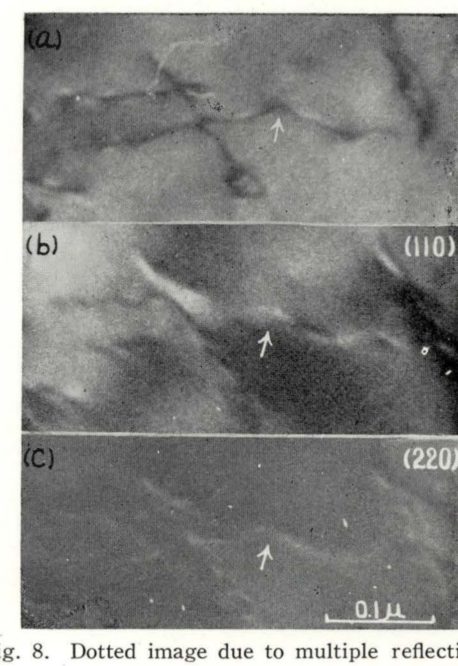

Fig. 8. Dotted image due to multiple reflections

3) The complex features of the dotted images, for instance, the image interposed between two black lines, as seen in Fig. 9, are due to multiple reflections.

Bending of the Specimen Owing to Dislocations:

Since the thickness of the specimen used is very small, about 1000 Å, it is expected that the specimen is bent by the dislocation for relief of the dislocation stress. Some of the image features may be affected by this phenomenon because of variation of the reflecting condition. When unlike dislocations are situated closely and parallel to each other, the dislocation stress will be relieved so easily that the surface of the region between them becomes nearly flat. Regions 1~6 in Fig. 10 are considered to correspond to such cases.

In Fig. 11, the position of the black contrast of intersecting dislocation image Y is interchanged from one side to the other at the intersection and also at A. In this case the index of the reflection of the image Y is different from that of the dark matrix.

Therefore, it is expected that the condition of the crystal around the dislocation line is quite similar to the case of the extinction contour due to the usual bending. A double image of dislocation X may result from the

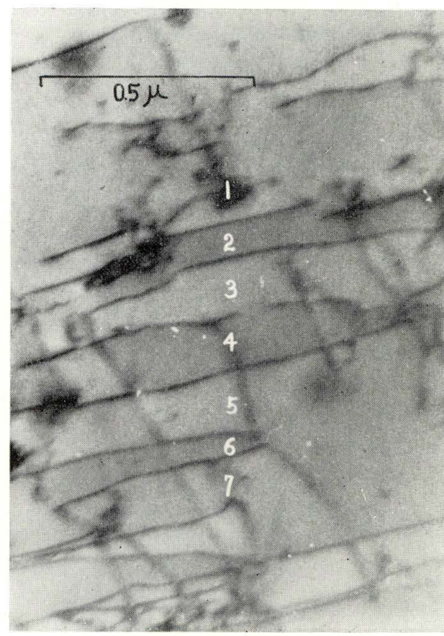

Fig. 10. Contrast of the region between dislocation images.

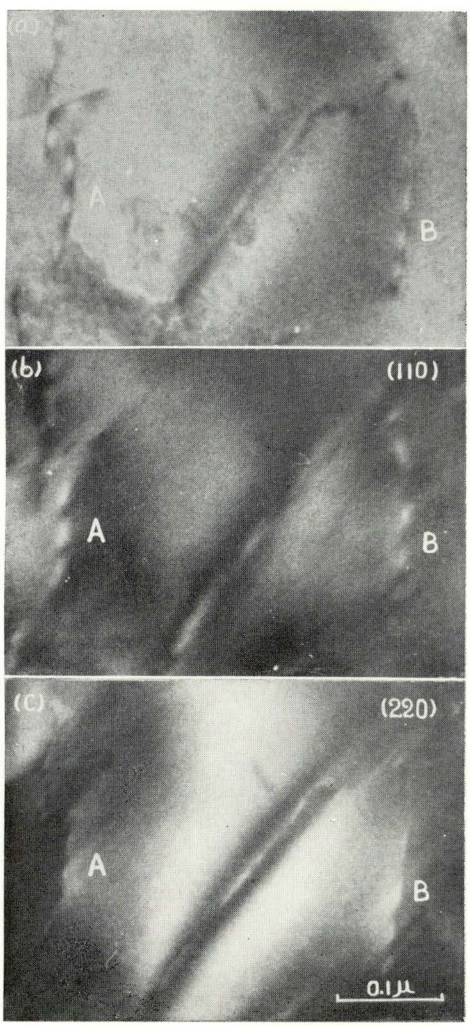

Fig. 9. Complex dotted image due to multiple reflections.

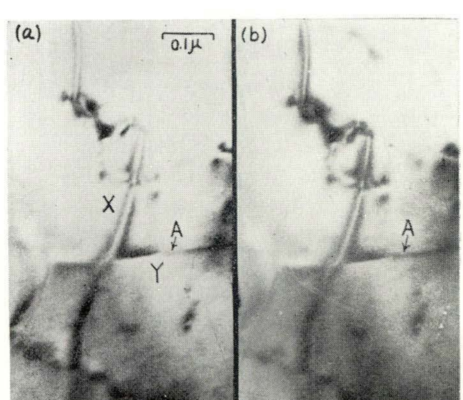

Fig. 11. Reversal of image contrast and double image at the intersecting dislocations.

local bending around the dislocation X, i.e., the sign of s (usual notation[1]) changed on both sides, whose separation is sensitive to the incident angle.

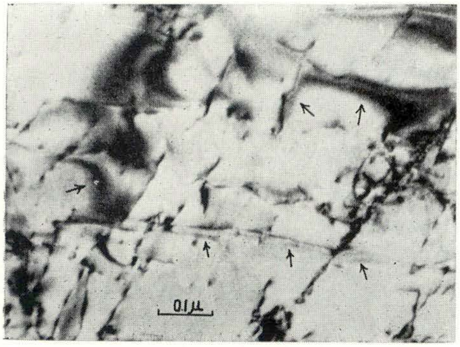

Fig. 12. Extinction contour due to the local bending.

Broad lines (↑) accompanying the dislocation images in Fig. 12 are also considered as a result of the local bending. At the left side of Fig. 12, curved extinction contours are observed in a region subdivided by two dislocation images.

It is disirable that in very near future most of the images observed in the present work could be elucidated by advanced diffraction theory.

References

1 P. B. Hirsch, A. Howie and M. J. Whelan: Phil. Trans. Roy. Soc. **A252** (1960) 499.

DISCUSSION

M.J. WHELAN: You can obtain long tails to the image profile of a screw dislocation if the Bragg condition is not exactly satisfied. The results of theoretical calculations for this case show that the intensity is above the background level for several extinction distances on one side and below background for a comparable distance on the other side. We have looked for this effect, and although one or two cases have been observed, we do not understand why we do not see it more frequently, since long dislocations must often be observed in the deviated condition. The pairs of long dislocations which you observed with the darker contrast between them might possibly be dislocations of opposite signs showing this effect.

H. FUJITA: I agree with your idea. But we think, there still be some possibility that the foil is bent by the dislocation stress when it is thin. In the case of iron and its alloys, we observed such long tails of the image pretty often. But in the case of aluminium foils, we scarcely observed them. And so, we consider that the contrast of matrix around dislocation may depend upon the thickness of the foil or the kind of the dislocation.

P.B. HIRSCH: Your observation that single and double images can be seen when two reflections are operating can be understood in terms of the simple kinematical theory. Double images will only be observed if either the sign of $\boldsymbol{g}\cdot\boldsymbol{b}$ or the sign of s changes for the two reflections (usual notation). If both quantitites change sign or do not change sign, both images appear on the same side of the dislocation.

H. FUJITA: In a double image in Fig. 3, one line may be considered to be main, and the other a subsidiary line of (110) reflection. Contrary to this, in a double image in Fig. 11 the white mid-portion of the image X in the upper part is continued to a black single image in the lower part. Furthermore, the sign of index of each one of the image lines changes from each other. Therefore, this is the case when the sign of s changes on both sides of dislocation for the two reflections.