Effect of Incoherent Waves on the Electron Microscopic Images of Crystals

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Electron micrographs are taken by placing the objective aperture at various positions. As the aperture is shifted from the position of the direct spot to that of a Bragg spot, the image of crystalline material changes gradually from the bright field image to the usual dark field image. Extinction contours and Pendellösung fringes are observed even when neither the direct wave nor a Bragg reflected wave passes through the aperture. It is pointed out that the absorption coefficient determined by the electron microscopy depends upon the size of the aperture of objective lens.

We studied the effect of diffuse scattering on the image of crystalline materials. Some of our results were already published in a recent issue of the Journal of the Physical Society of Japan[1]. However, we begin with some of the published results and then give recent advances.

Fig. 1 shows various positions of objective aperture in the electron microscope. The positions for the bright field (a) and the usual dark field (b) are used in routine work of electron microscopy. Since, however, our purpose is to study images formed by diffuse scattering, we took pictures by placing the aperture at positions (c), (d), etc. where no sharp spot is included in the objective aperture. At such positions, no wavewhich is coherent with the direct wave passes through the objective aperture. The image is formed solely by the waves which are incoherent with the direct wave.

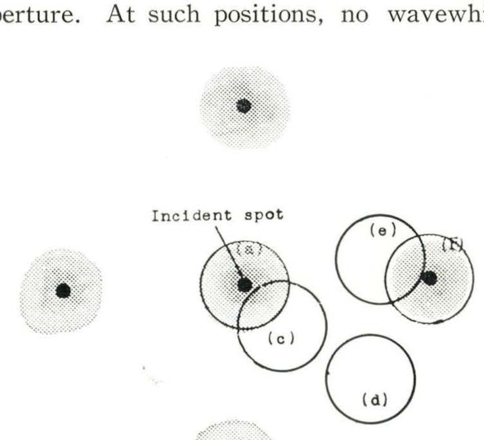

Fig. 1. Various positions of objective aperture (a) Bright field (with the incident spot), (b) Usual dark field (with a diffraction spot), (c), (d) and (e) Special dark field (without any diffraction spot).

Fig. 2 shows Pendellösung fringes of magnesium oxide. Pictures were taken by placing the objective aperture at various positions as indicated in the figure. The bright field image (a) and the usual dark field image (b) are well-known. The picture (c) was taken by placing the aperture just beside the incident spot. The background of (c) is perfectly dark indicating that (c) is a dark field image. However, the fringes in (c) is almost the same as those in the bright field image (a). There is no doubt that the fringes in (c) is produced by incherent waves*. It has not been known that incoherent waves behave according to Pendellösung similar to the coherent wave.

Fig. 3 shows a series of extinction contours of aluminum crystal. This series was taken by shifting the objective aperture gradually from the position of the bright field to that of the usual dark field. The gradual change of contrast in images can be seen in the series.

Fig. 4 illustrates that a bright field image (or an usual dark field image with a diffraction spot) is a superposition of two images: one is the image formed by the coherent wave (c-image) and another, that formed by the incoherent waves (i-image). The c-image is almost independent of the size of the aperture because the coherent waves are concentrated

* Exactly speaking, waves incoherent with the direct wave.

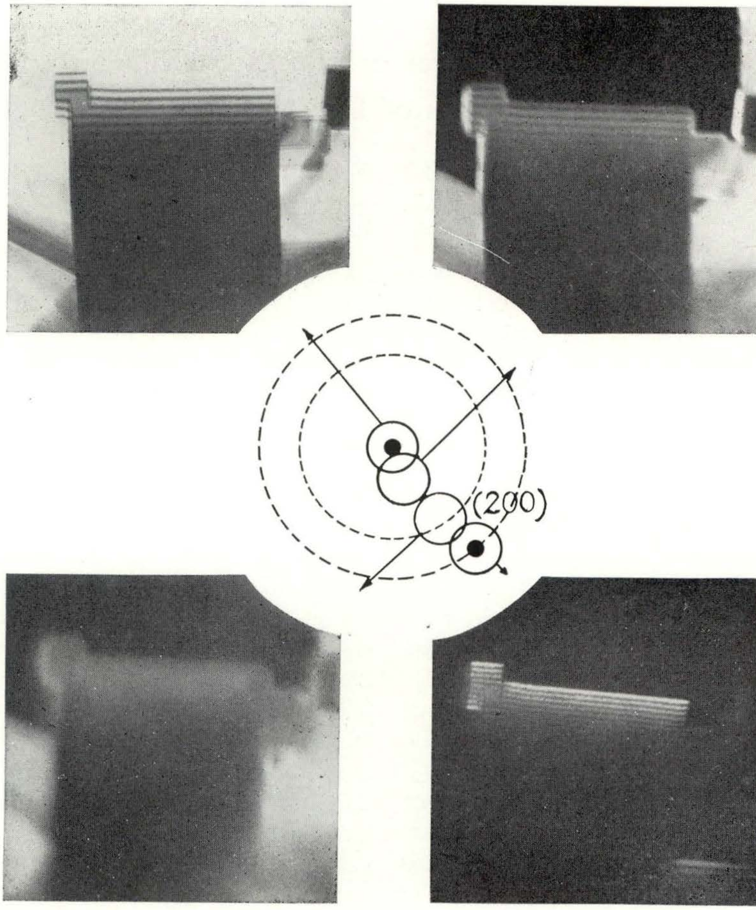

Fig. 2. Pendellösung fringes of magnesium oxide crystallites, ×90,000. Pictures taken at various aperture positions (Difference of spacing in (a) and (c) may be due to change of crystal orientation).

at a sharp spot while the i-image does depend on the aperture size because the incoherent waves are diffuse. The intensity of c-image can be explained by the current dynamical theory, but the intensity of i-image is still theoretically unknown. We have found by experiment that the intensity of i-image is something like that shown in (c) of Fig. 4.

By the use of dynamical theory with absorption, Cambridge group[2] has recently succeeded in explaining the general feature of extinction contours, stacking fault fringes and dislocation images. In the quantitative treatment, however, it is expected that the dynamical intensity formula deviates from the observed intensity of bright field image (or usual dark field image) even when the absorption effect is taken into account. Particularly for thick part of the crystal, the i-image prevails over the c-image. Even when empirical values of $v_0{}^i$ and $v_h{}^i$ are determined, they depend on the size of the objective aperture and does not agree with the values determined by electron diffraction.

The difficulty met by Kohra and Watanabe[3] in the experimental determination of $v_0{}^i$ and $v_h{}^i$ may be due to the effect of i-image.

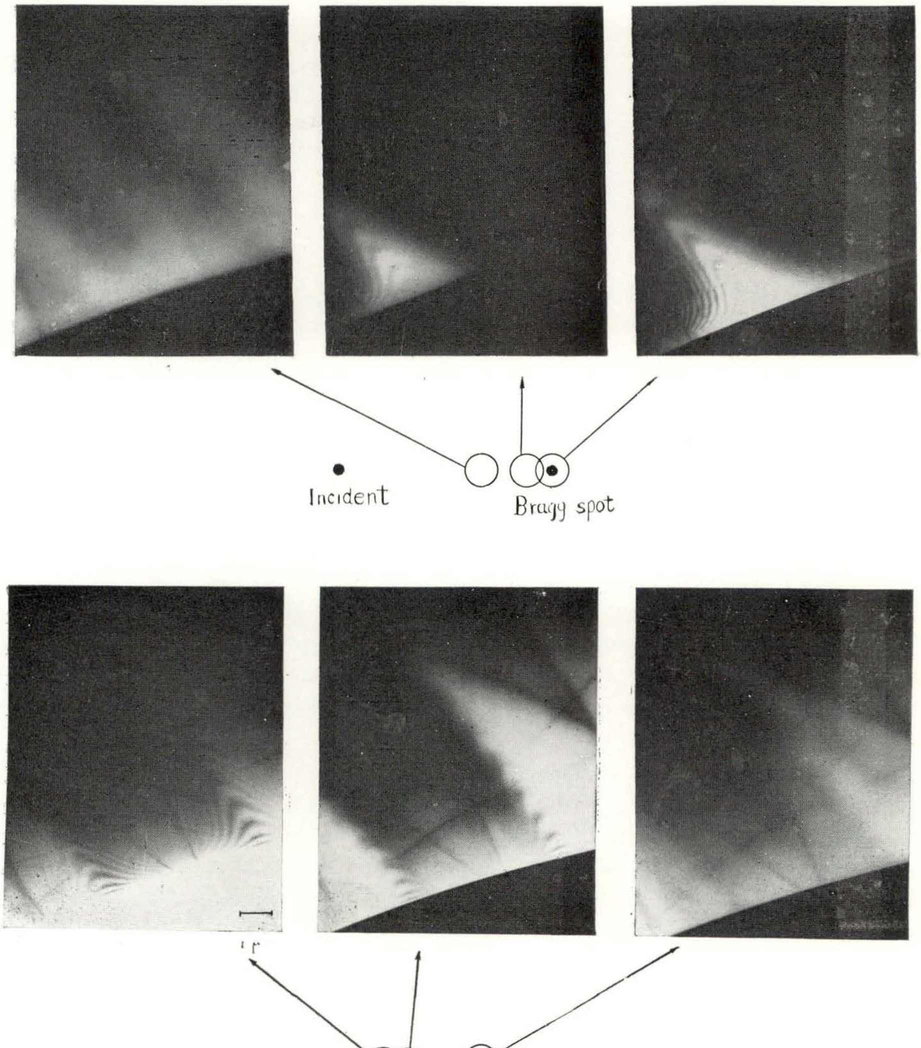

Fig. 3. Extinction contours of aluminun crystal. Pictures taken at various positions of objective aperture.

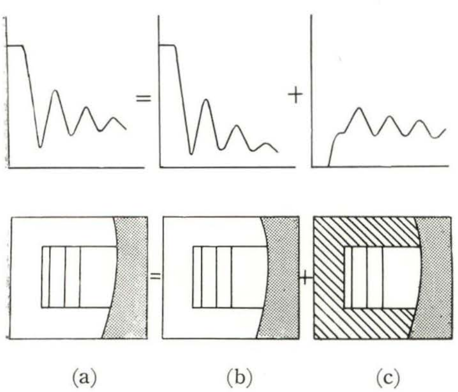

Fig. 4. Illustrating the nature of bright field image. A bright field image (a) is the superposition of c-image (b) and i-image (c).

References

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2 A. Howie and M. J. Whelan: *Proc. Eur. Reg. Conf. on Electron Microscopy, Delft* **1** (1960) 194; Proc. Roy. Soc. **A263** (1961) 217. H. Hashimoto, A. Howie and M. J. Whelan: *Proc. Eur. Reg. Conf. on Electron Microscopy, Delft* **1** (1960) 207; Phil. Mag. **5** (1960) 967.
3 K. Kohra and H. Watanabe: J. Phys. Soc. Japan **16** (1961) 580.

DISCUSSION

H. NIEHRS: The diffraction diagram of only one crystal edge consists of a transmitted and diffracted spots, each of which, however, are splitted by multiple refraction. Therefore, I should like to ask you how large may be the angular widths and distances of neighbouring circles (a) and (b), or (d) and (e) of the divergent beam used for your microscopy?

Y. KAMIYA: The angular width of the objective aperture is about 1.5×10^{-3} rad. The distance is not measured accurately. But we have proved by experiment that no wave coherent with the direct wave have taken part in the formation of image. Would you please refer to our paper J. Phys. Soc. Japan, **16** (1961) 1361.

H. WATANABE: We obtained electron micrographs of Al-film by using only the elastically scattered electrons or by using only the inelastically scattered electrons with a certain amount of energy loss. The instrument may be called an "*energy selecting electron microscope*." In the micrographs by inelastically scattered electrons we found the equal-thickness fringes. This also is believed to be a direct evidence for the interference of inelastically scattered electrons.

H. RAETHER: I understand that the interference effect of the electrons outside the primary beam and outside the Laue spot occurs from electrons incoherent with the primary beam. In our experiments on the energy analysis of Kikuchi lines we had to assume that the primary beam obtains an appreciable divergence after entering the thin film, which is not understandable. The angular deviation of the intensity of the first loss shows a very small angular width ($\theta_{1/2}=2\times10^{-4}$), whereas the energy analysis in Si shows a high proportion of the first loss at $\theta=10^{-2}$. Such incoherent waves would given an explanation of the Kikuchi lines. Do you agree and have you an idea of the angular dependence of these incoherent waves?

Y. KAMIYA: I also think that our results would be intimately related to Kikuchi patterns.