Contrast of Kossel Patterns in Electron Diffraction

F. Fujimoto

College of General Education, University of Tokyo, Tokyo 153, Japan

and G. Lehmpfuhl *

Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, West-Germany

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Electron diffraction patterns from a Si crystal taken with a convergent beam of large angular aperture (Kossel pattern) are compared with the diffraction pattern taken with a hollow cone convergent electron beam. For thin crystals the patterns are complementary. This behaviour is discussed.

Kossel-Möllenstedt patterns, obtained by using a convergent electron beam, are useful for studying the diffraction phenomena of electrons by crystals [1]. The convergent beam usually has an angular divergence of the order of the smallest Bragg angle. A Kossel-Möllenstedt pattern obtained from a silicon crystal with the surface parallel to the (100) plane is shown in Fig. 1 **, where the electron energy was 100 keV. The estimated crystal thickness was about 2000 Å. Although we can see the faint Kikuchi bands outside the circles of the Bragg reflections in Fig. 1, the intensity of the elastic scattering is much stronger than that of the inelastic scattering.

When the beam divergence is made much larger than the Bragg angle, as shown in Fig. 2 a, the circles of the Bragg reflections overlap and we obtain the Kossel pattern [2]. The Kossel pattern observed from the same part of the specimen as that for Fig. 1 is shown in Fig. 3 a, where the beam divergence 2α was about 6° ($\Theta_{220} = 0.55^\circ$ at 100 keV). Here, the fine-structure observed in Fig. 1 vanishes and a Kikuchi-like pattern appears, although the elastic scattering is still the main contributor to the pattern.

For the study of the relation between the Kossel and the Kikuchi patterns the circular aperture was replaced by a ring aperture, and the specimen was irradiated with a hollow cone beam, as shown in Figure 2 b. The inner angle 2α of the hollow cone was about 7° and the outer angle 2β was about 10°. Figure 3 b shows the pattern taken by this method from the same part of the specimen as that for Figure 3 a. We call this the "ring pattern". The part with strong intensity

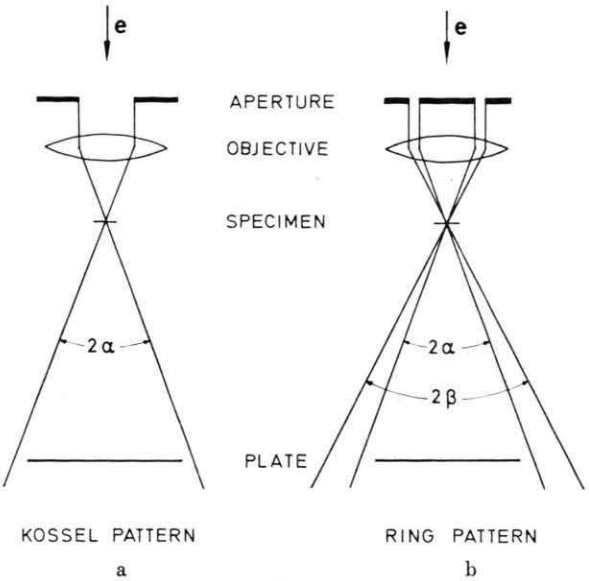

Fig. 2.

on the edge of Fig. 3 b is due to the incident beam and due to electrons scattered elastically. The pattern in the vicinity of the center in Fig. 3 b consists of electrons scattered inelastically, and is practically identical to Kikuchi patterns, which are observed at large scattering angles in the usual way.

Figures 3 a and 3 b show that the contrast of the Kossel and ring patterns are just reverse. This can be understood in the following way. In our experimental conditions the observed area at the center of the diffraction patterns corresponds to an angular aperture of only a few degrees. We consider a convergent beam with an extremely large aperture, say $2\alpha = 120^\circ$. If the crystal is so thin that only the innermost part of this large cone contributes to the intensity in the observed area, it can be seen easily that no contrast should appear in the observed area. (The intensity distribution over the large angle of the incident beam is constant. In an area near the axis of the cone of illumination a modification of the intensity of the transmitted beam due to diffraction should be compensated by reverse processes. This compensation does not occur in the case of a Kikuchi pattern because of the angular intensity distribution of the inelastically scattered electrons.) This effect was already mentioned and discussed by Menzel-Kopp [3] in a convergent-beam experiment. If the 120° cone is separated into the 6° cone and the hollow cone of the remainder, it is seen at once that the contrast obtained in the observed area by using the 6° cone should be exactly complementary to that obtained by using the hollow cone. In our experiment the hollow cone is not

* Abteilung Prof. Dr. K. Molière.
Reprint requests to Dr. G. Lehmpfuhl, Fritz-Haber-Institut der Max-Planck-Gesellschaft, *D-1000 Berlin 33 (Dahlem)*, Faradayweg 4–6.

** Figures 1, 3 and 4 on page 1930 a, b.

exactly complementary to the 6° cone, but it appears to be sufficient to get practically complementary pictures for a thin crystal as shown in Figs. 3 a and b.

The contrast of the Kossel pattern does not essentially change when the thickness of the crystal increases and the inelastic scattering becomes dominant (Fig. 4 a). In fact, it is well-known that Kikuchi patterns observed from a thick crystal always show deficit bands at the center. In this case, the ring pattern taken by using the same ring aperture as before, shown in Fig. 4 b, is almost the same as Figure 4 a. According to the above consideration using the 120° cone, this indicates that due to the increase of the angular range of the scattering intensity with the thickness, which is caused by multiple inelastic scattering, the outer angle β of the hollow cone used in this experiment was too small. If we could use a hollow cone with an outer angle 2β much larger than 10°, we would expect the ring pattern again to be just complementary to the Kossel pattern in Figure 4 a. This is, however, technically very difficult due to the spherical aberration of the focussing lens.

The relation between the Kossel and the Kikuchi patterns has been applied to the study on electron channeling and blocking by the present authors and coworkers [4].

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[1] Cf. e. g. P. Goodman and G. Lehmpfuhl, Z. Naturforsch. **20 a**, 110 [1965].
[2] P. Goodman, Acta Cryst. **A 28**, 92 [1972].
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[4] F. Fujimoto, K. Komaki, H. Fujita, N. Sumita, Y. Uchida, K. Kambe, and G. Lehmpfuhl, Proc. of 5th Intern. Conf. on Atomic Collision in Solids, Gatlinburg, Tenn., USA, Sept. 1973.

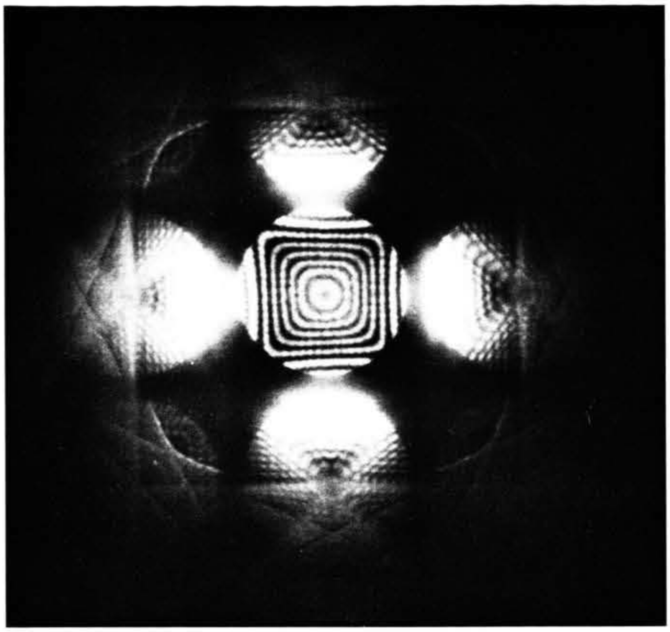

Fig. 1.

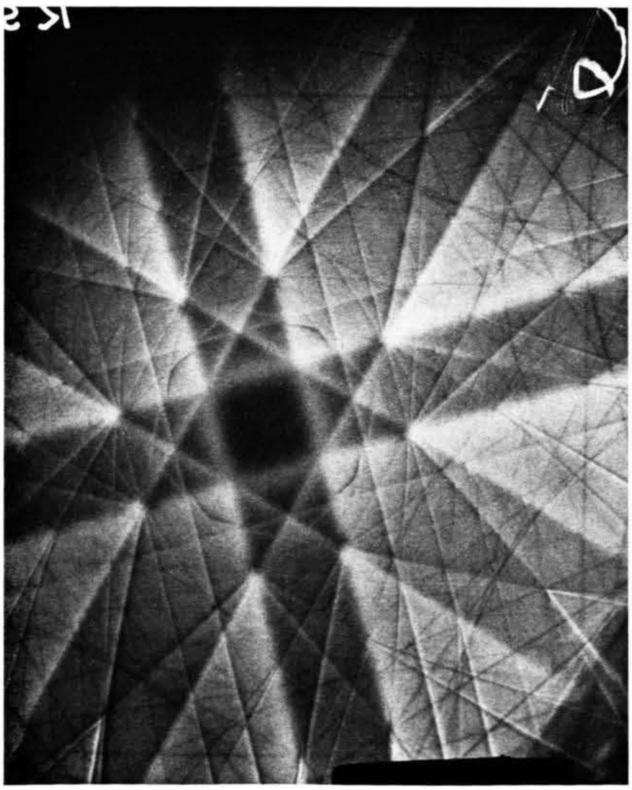

Fig. 3 a.

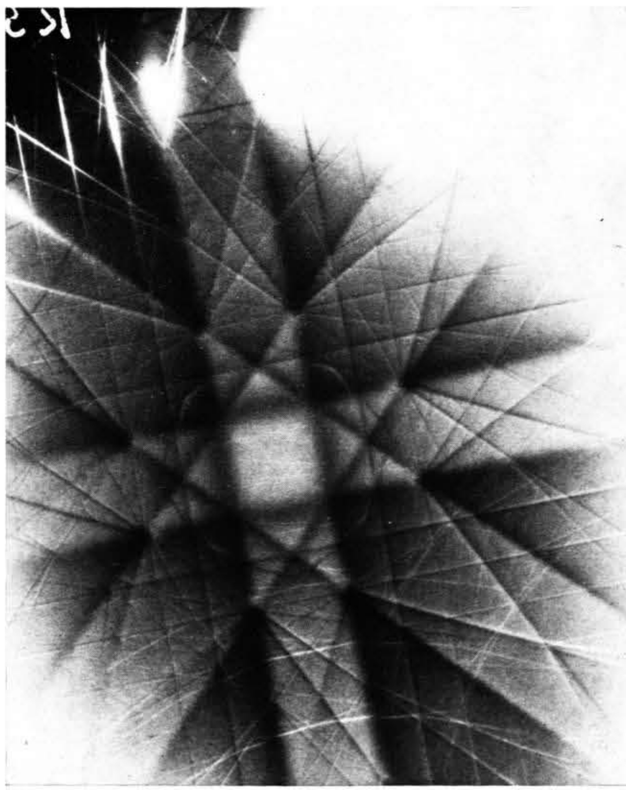

Fig. 3 b.

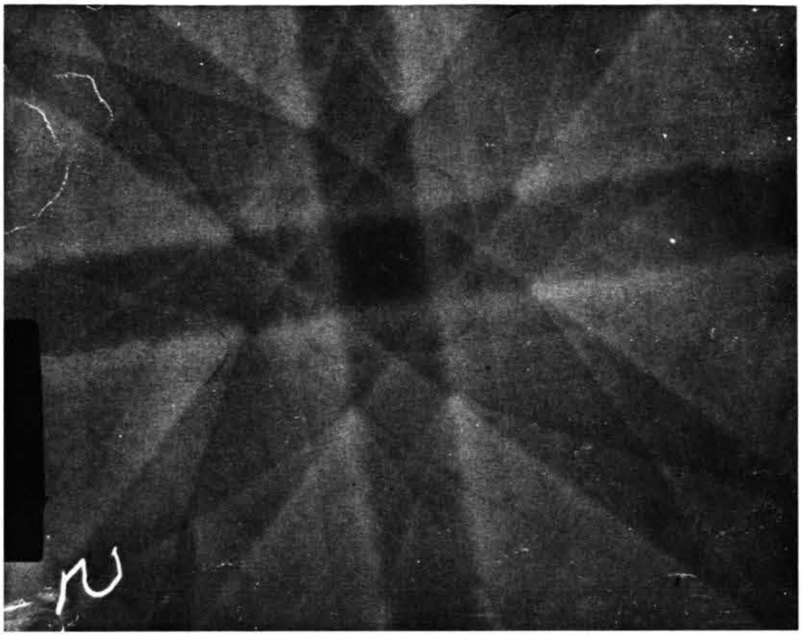

Fig. 4 a.

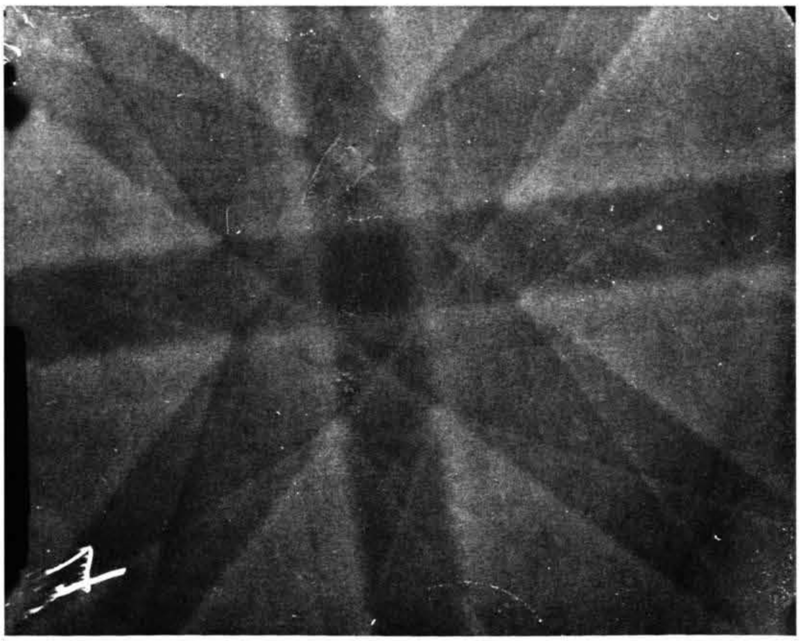

Fig. 4 b.

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