Multistereo Synchrotron X-ray Topography

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Dedicated to Prof. G. Hildebrandt on the occasion of his 60th birthday

Any two of several reflection or transmission x-ray topographs taken simultaneously with polychromatic synchrotron radiation form a stereo pair. Multistereoscopic transmission and reflection patterns of topographs taken from a silicon and iron-silicon crystal are presented. The directions and depths of defects are calculated from the measurements on the images in two symmetric topographs.

Three methods have been used to obtain stereo pairs of x-ray diffraction topographs. Lang suggested [1] that a three-dimensional picture of e.g. dislocations within the volume of a crystal slab may be obtained using a pair of the hkl and $\bar{h}\bar{k}\bar{l}$ transmission topographs [2]. In the second method developed by Haruta [3] the same set of reflecting planes is used but the crystal is rotated about the normal of the reflecting planes before taking the second topograph. The third stereoscopic imaging technique described by Hamill and Vreeland [4] is based on anomalous transmission of x-rays through nearly perfect thick crystals. A stereo pair consists of the diffracted and transmitted beam topographs obtained simultaneously on the film placed parallel to the exit surface of the crystal.

In this work it is shown how a large number of stereo pairs of high resolution x-ray topographs are obtained simultaneously with polychromatic synchrotron radiation and in a short exposure time. No rotation of the sample is needed. The method applies to the reflection geometry as well as to transmission geometry. The synchrotron x-ray topography method itself is not new. It has been used since 1973 [5]. The fact that it is a multistereoscopic imaging technique is a new important aspect. The first results obtained with the stereotechnique have been published in [6].

The transmission topographs of this work are from a 0.35 mm-thick silicon single crystal. They have been taken with synchrotron radiation from the DESY electron synchrotron [5, 7]. Fe-3 wt% Si

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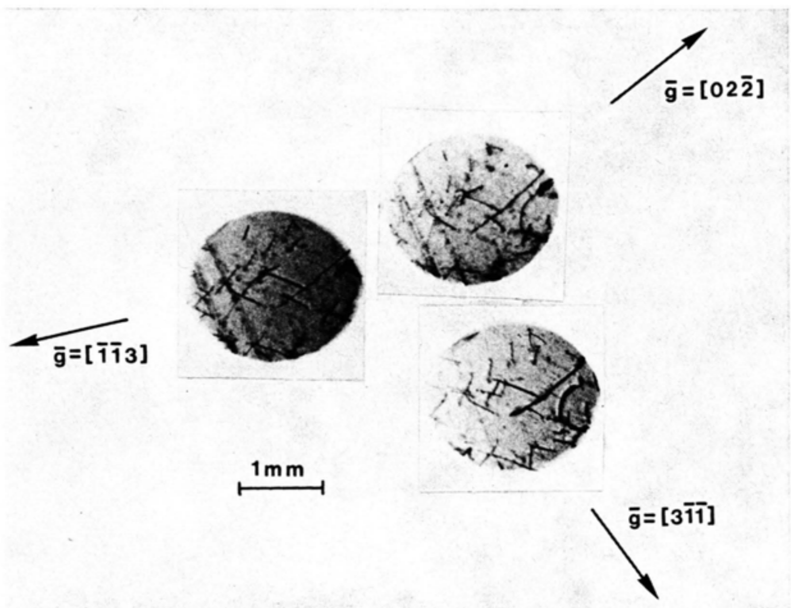

Fig. 1. A Laue pattern consisting of three stereo pairs of enlarged transmission topographs taken from a 0.35 mm-thick silicon wafer. The [111] normal of the sample surface is slightly inclined from the direction of the incident synchrotron radiation beam. The topographs have been taken with radiation from the DESY electron synchrotron (Hamburg), the maximum electron energy of which was 7.2 GeV. The exposure time on a Kodak R film was 30 s.

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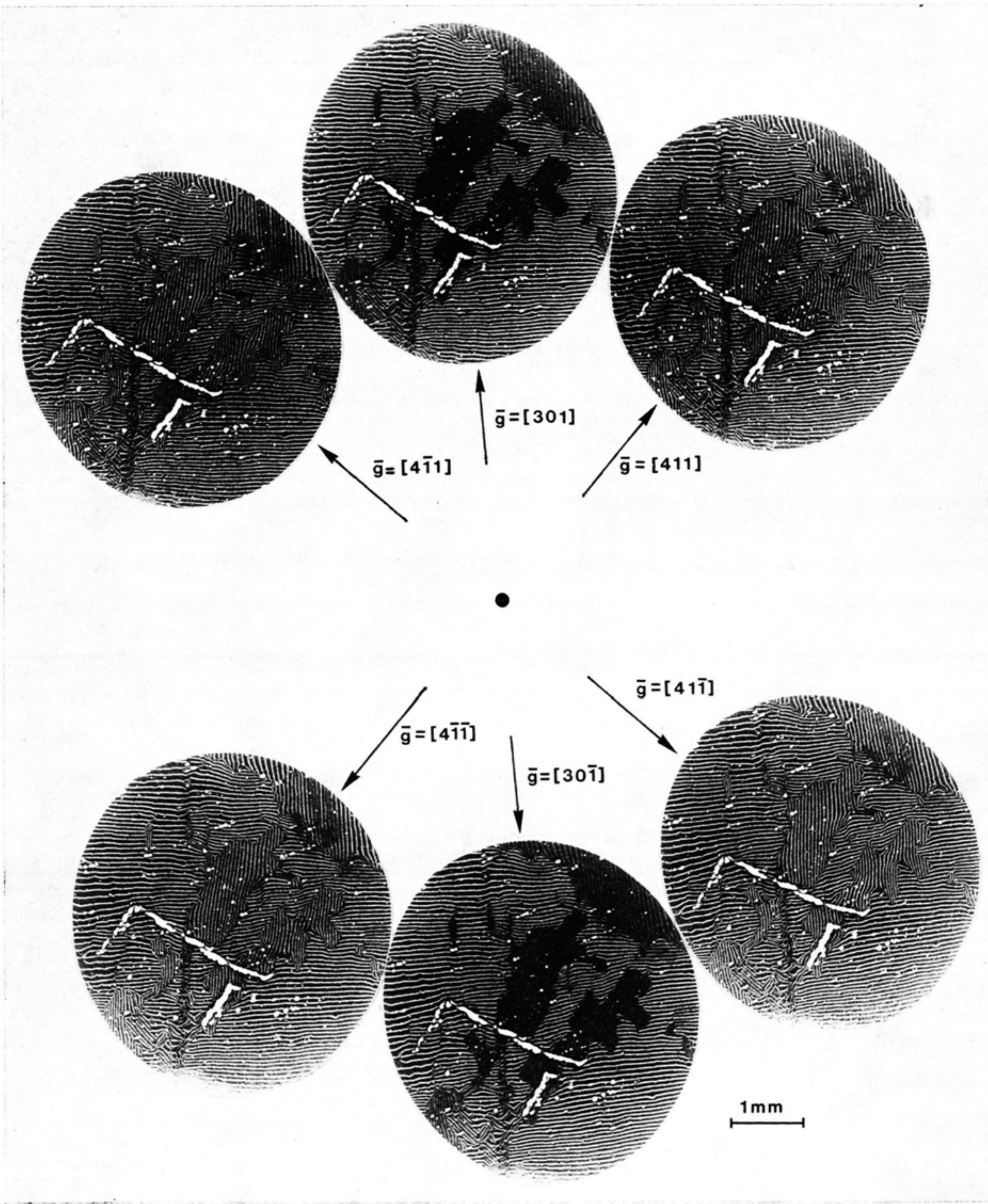

Fig. 2. A Laue pattern of six enlarged back-reflection topographs from an iron-3%silicon crystal taken with synchrotron radiation from the DORIS storage ring simultaneously on one film. Altogether 15 pairs of topographs may be viewed stereoscopically from suitable directions. The accelerator conditions were 3.3 GeV, 40 mA; exposure time 60 s.

polycrystalline platelets, which were 0.15 mm thick, served as samples for the reflection stereo topography with synchrotron radiation.

Figure 1 shows three transmission topographs from the silicon wafer. After enlargement the prints are brought closer to the centre of the pattern so that their relative angular positions and their relative distances from the centre are kept the same as in the original x-ray film. When any of the three possible pairs of topographs are now viewed stereoscopically in the direction perpendicular to the lines joining the pairs a three-dimensional picture is seen. In the upper left corner of the topographs a row of five dislocations extend from the entrance to the exit surface of the crystal.

Fig. 2 shows six reflection topographs of the Fe-3 wt% Si crystal. They are enlarged prints which have been arranged in a similar fashion as the three topographs of Figure 1. There are altogether 15 stereo pairs in Figure 2. Each of the 15 stereo pairs can be viewed in the direction perpendicular to the line joining the pairs. E.g. to see the pair $(4\bar{1}\bar{1}, 411)$ stereoscopically the picture must be turned clockwise 45° about the normal of the paper.

The horizontal and vertical lines in the regularly shaped regions of the topographs of Fig. 2 are images of magnetic domain walls [8]. In the three-dimensional picture these lines are on the surface above the white spots. In [6] it was shown how the depth of 25 μm of a spot below the surface of the sample was calculated from the measurements on a pair of symmetric topographs.

In Figs. 1 and 2 not all possible stereo pairs are presented. It can be claimed that *any two* topographs of a Laue pattern form a stereo pair. It is not even necessary to pick up the pair from the same Laue transmission or reflection pattern to obtain a stereo image. A three-dimensional picture is evidently seen also when the film or plate is not parallel to the surface of a plate-like sample.

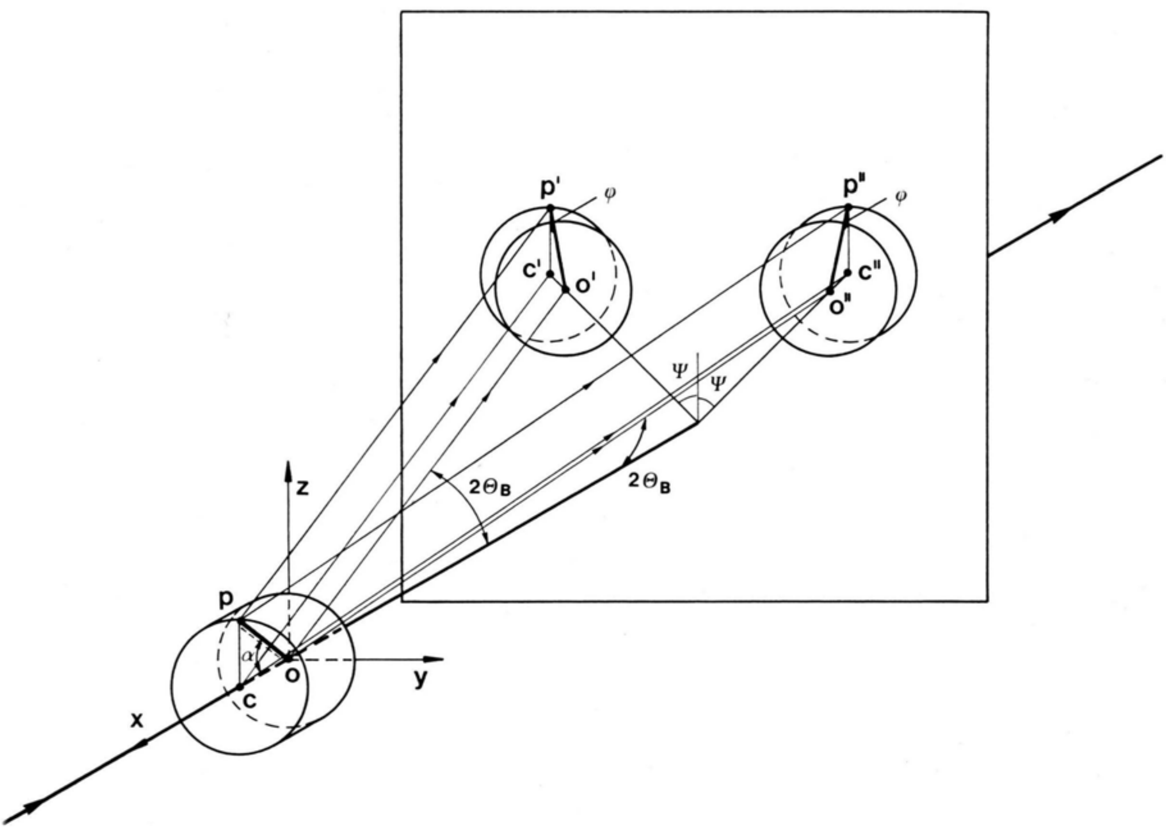

Fig. 3. Projections of a straight line (defect) op on two topographs having the same Bragg angle θ_B. The line op is in the vertical plane. The topographs are taken on a film placed parallel to the entrance surface of the sample and they are symmetrically located with respect to the vertical direction.

Figure 3 shows schematically two transmission topographs resembling those in Figure 1. Although the sample is drawn as a thick cylinder, it is assumed that the image formation is purely kinematic. The circular entrance surface of the cylinder centered at c is imaged as a circle c' and c'' on the film. The Bragg angle is the same θ_B for the two topographs, which are symmetrically located on the film. The lines joining c' and c'' with the point in which the central ray of the direct beam hits the film form an angle ψ with the vertical direction. The images of the circular exit surface o are obtained by parallel projection in the same manner as those of the entrance surface. They are circles o' and o''.

A linear defect op, which is in the vertical plane, extends from the exit surface to the entrance surface of the sample. The images of the straight line in the topographs are $o'p'$ and $o''p''$. They form an angle $\varphi (= \sphericalangle c'p'o' = \sphericalangle c''p''o'')$ with the vertical (pc, $p'c'$ or $p''c''$). For $\sphericalangle poc = \alpha$ it is easily obtained

$$\tan \alpha = \frac{\sin(\psi - \varphi) \tan 2\theta_B}{\sin \varphi} . \qquad (1)$$

Equation (1) can now be used for the determination of the direction angle of the middle dislocation in the row of the five dislocations in Figure 1. The Bragg angle for the $\bar{1}\bar{1}3$ and $3\bar{1}\bar{1}$ reflections is $\theta_B \approx 8°$, $\psi \approx 60°$, and $\varphi \approx 13°$. From Eq. (1) $\alpha \approx 43°$ is obtained. The calculated direction is rather close to [101].

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