A High-Resolution Section Topograph Technique Applicable to Synchrotron Radiation Sources

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Abstract

Asymmetric Bragg reflection from the surface of a plane crystal monochromator is employed to provide the spatially narrow beam (width less than 10 μm) required for high resolution in X-ray section topographs. Details are given of apparatus in which the monochromator is traversed back and forth to even out local irregularities in its reflecting power, and a precisely positionable screen is interposed between the monochromator and specimen to cut out radiation reflected from imperfections below the monochromator surface. The system was designed to be tolerant of some imperfection in the specimen to cut out radiation reflected from imperfections below the monochromator surface. The system was designed to be tolerant of some imperfection in the monochromator and this objective was achieved. With Cu Kα̊ radiation, a natural diamond (111) face and the asymmetric 220 reflection, a lateral compression of the beam by a factor of 22-6 was obtained. Section topographs are exhibited in which the spatial width of the incident beam is only 7 μm. A benefit of this technique is the possibility of reducing the wavelength bandwidth effective in recording the topograph to less than that of the Kα̊ emission profile, and hence of reducing the contribution of dispersion to diffusion of the topograph image. The applicability of the method to synchrotron radiation sources is discussed.

1. Introduction

When surveying the diverse applications of X-ray topography to the mapping of crystal-lattice defects, one finds that the projection topograph (or traverse topograph) method (Lang, 1959) is more frequently used than the section topograph method (Lang, 1957). If thin, lightly absorbing crystals constitute the specimen material and the density of defects is low, the straightforward geometric interpretability of the projection topograph image and the large specimen-area coverage possible in a single exposure explain the popularity of this topographic technique. However, it is the section-topograph image that contains the fundamental diffraction pattern which, after spatial integration, forms the projection topograph image. It follows from the more basic character of the section topograph image that attempts to match theory with experimental observation have concentrated upon the synthesis of section topograph images, both for perfect and for imperfect crystals. Authier (1977) has presented an account of these endeavours; and to his review one might add some noteworthy recent work, the simulation of section topograph images of the Dijkstra–Martius ferromagnetic domain structure in silicon–iron sheets (Nourtier, Taupin, Kléman, Labrune & Milat, 1977). Studies such as this require high-resolution section topographs to provide the data to compare with the simulations. As a rule, the investigator must turn to the section topograph to fulfill any of the following experimental requirements: (1) highest capability for resolving individual lattice defects when their distribution within the specimen is dense, (2) highest sensitivity for detecting single defects which produce weak, localized diffraction contrast (under conditions that the angular width of the illumination of the specimen exceeds the angular range of reflection by the specimen crystal when it is perfect); (3) recording of Pendellösung fringe phenomena, particularly those associated with fault surfaces; (4) direct measurement of the depth below the specimen surface of a given defect (or a direct exhibition of qualitative differences between defect content in the specimen interior compared with that close to the specimen surfaces); and (5) recording of weak, disorder diffuse reflections. For the best overall resolution in section topography the requirements are: (a) an incident beam which is spatially very narrow; (b) relatively high diffraction angles to give section topograph images wide enough for measurements across them to be made reliably; and (c) as long a wavelength as the specimen absorption will allow in order to gain resolution from the decrease in extinction distance that accompanies increase in wavelength. However, when conditions (a), (b) and (c) apply it may well happen that image smearing due to dispersion of the natural wavelength spread of the Kα̊ emission line will contribute significantly to the limitation of topographic resolution. In this paper we describe how an asymmetrically reflecting plane crystal monochromator can be used as a spatial beam compressor to provide the narrow incident beam required for high-resolution section topograph experiments. We give details of apparatus constructed to operate this
technique and designed to fit easily on a standard type of X-ray topograph camera. A particular feature of the design is tolerance of lack of perfection in the monochromator crystal. Furthermore, we show that among benefits accruing from the use of incident radiation monochromatized by crystal reflection is the possibility of limiting the wavelength bandwidth used and thereby reducing loss of topographic resolution due to dispersion. These advantages will carry over into embodiments of the technique appropriate for use with synchrotron sources, and should be particularly beneficial for diffuse reflection topography using such sources.

2. Apparatus

2.1 Principles of the method

Fig. 1 shows in schematic fashion the X-ray optical configuration. A relatively wide incident beam (spatial width, \(S_r\), about 200 \(\mu\)m) is transformed into a narrow beam (spatial width, \(S_x\), about 10 \(\mu\)m) by the monochromator \(M\), using reflecting planes dipping at an angle \(\varphi\) to the crystal surface. This reproduces the ‘condensing monochromator’ geometry of Fankuchen (1937). The ratio \(S_x/S_r\) is \(\sin(\theta_M + \varphi)/(\theta_M - \varphi)\), \(\theta_M\) being the Bragg angle for the monochromator reflection. The ability of asymmetric Bragg reflection to produce beam expansion or contraction has been exploited in X-ray image magnifiers (e.g. Boettinger, Burdette & Kuriyama, 1979) and reducers (Mardix & Lang, 1979.). The narrow beam reflected from \(M\) becomes the incident beam for the specimen crystal \(N\), falling on it at \(O\) and generating the energy-flow triangle \(OAB\). The customary diffracted-beam section topograph is obtained by recording the reflected beam \(RR'\). Moreover, the exceptionally clean nature of the beam \(OT\) facilitates recording of the direct-beam section topograph also, by placing a photographic plate perpendicular to the beam \(TT'\). The specimen \(N\) is shown deviating rays in the opposite sense to \(M\), i.e. in the \((m, -n)\) setting of double-crystal spectrometer notation: \(N\) can equally well be oriented to deviate rays in the same sense as \(M\), in the \((m,n)\) setting, as will be discussed below.

Few crystals can be grown highly perfect and in addition be capable of having flat surfaces prepared on them free from damage such as would manifest itself by X-ray diffraction contrast. Silicon, germanium and quartz belong to this elite, but only silicon and germanium can routinely be obtained with zero dislocation density and free from appreciable local variations of X-ray reflecting power arising from impurity banding or fault surfaces. A prime objective of our work was to enable crystals of lesser perfection to serve satisfactorily as condensing monochromators. One part of our procedure is to arrange for the monochromator to be continuously traversed back and forth during exposure, with the direction of travel oriented accurately parallel to the crystal surface in order that there should be no sideways oscillation of the reflected beam. A travel range of about ten times the width \(S_t\) is found to be highly effective in averaging out random local variations of reflectivity of \(M\). (It would, of course, not be effective for some non-random distributions of defect outcrops: indeed it would not help at all if there were, for example, some dislocation-rich slip bands outcropping at the surface of \(M\) in horizontal traces, i.e. parallel to the direction of travel.)

A second essential component in the experimental set-up is the X-ray absorbing screen \(P\) placed between \(M\) and \(N\). This consists of a ground tungsten pin which is brought into approximate tangency with one margin of the surface-reflected beam from \(M\), as shown in Fig. 1. Attached to the pin is a vane of thin lead sheet sufficiently wide to intercept unwanted radiation scattered from any depth within \(M\). Imperfections such as dislocations outcropping at or in proximity to the surface of \(M\) include a ‘kinematic scattering’ component in their total diffraction contrast. For rays involved in this component the rate of attenuation with depth below the monochromator surface is determined more by the normal X-ray absorption coefficient than by the (much higher) Bragg-reflection extinction coefficient. If there is a significant fraction of more penetrating, harmonic radiation in the beam reflected by \(M\), then this radiation will be kinematically scattered from defects deep within \(M\), and emerge from \(M\) as rays widely displaced laterally from \(OA\). All such undesired rays are completely stopped by the pin and its attached vane. Proper positioning of \(P\) ensures that the beam \(OA\) has both margins sharply defined.

2.2 Practical design

The layout of the principal components involved in the technique is shown in Fig. 2. The special components needed were designed to be attached easily
to a topograph camera of standard form. This camera has fine adjustments for angle control of both the usual specimen axes (ω axis) and the axis (2θ axis) that carries the two arms upon which the X-ray counter and the diffracted-beam slit assembly are respectively mounted. The angle between these arms is variable: for normal X-ray topographs it is usually 90° but in the present configuration it is set at 180°. These two rotating arms together with the fixed arm which points towards the X-ray source and carries the collimator assembly for the incident beam are topped by parallel rails (in the style of optical benches) on which component carriers, of vee-groove and flat design, can be clamped where desired. Fig. 2 is a view looking towards the X-ray source: in the background is the housing, I, of the incident-beam slit assembly, and S₁ represents the relatively wide incident beam that was shown in Fig. 1. The monochromator crystal M occupies the position usually taken by the specimen crystal, being mounted on the ω axis via the goniometer head G₁, rotatable spindle F₁ and traversing mechanism T. To simplify the drawing it is assumed that 2θₛ is close to 90°, the beam reflected by M being deviated to the right in the plane of the drawing. The narrow beam issuing from M grazes the pin P, undergoes diffraction by the specimen N and is recorded on photographic plates held in cassettes such as E. [The cassette, as drawn, is receiving the beam TT' (Fig. 1.)] The specimen N is mounted on a goniometer head G₂ which is suspended inverted via the spindle F₂ from the beam B. This beam, together with the vertical pillars V₁ and V₂ and the base plate D (upon which stand the cassettes) constitute a rigid frame which we call the 'bridge'. It is mounted on standard carriers C₁ and C₂ clamped to arms A₁ and A₂ which are carried by the 2θ axis. The distance between M and N can be varied by sliding C₁ and C₂ along the arms A₁ and A₂, the plate D possessing a large notch cut away so that it does not collide with G₁ in any setting. By rotating F₁ relative to the traversing mechanism T, the face of M can be set parallel to the traverse within the tolerance desired (about 0.5 mrad). Both pillars V₁ and V₂ are pierced by apertures O₁ and O₂ which are useful for optically checking the alignment of M, P and N, and are essential for transmitting the beam reflected by M, whether deviated to the right or left. In Fig. 2, the beam passes through O₂ and is received by the X-ray counter X₁ by means of which the reflecting condition of M is monitored. The specimen N is oriented for Bragg reflection with the aid of a second counter X₂, which will be on the far side of the 'bridge' when M and N are in the (m, n) setting, and on the near side when they are in the (m, -n) setting. The lever H clamped to the spindle F₂ permits angular adjustment of N to a fineness of about 1 mrad; finer adjustment (to 1° of arc) is provided by the radius arm and tangent screw which are available on the instrument for control of the orientation of A₁ and A₂.

The pin P must be adjustable in three ways: (1) its location along the line joining M and N must be controllable; (2) its motion along a horizontal direction normal or nearly normal to the beam reflected from M must be controllable to 1 μm; and (3) its tilt must be controllable so that it touches the top and bottom of the reflected beam simultaneously. These motions are provided as follows. The pin P (and its attached vane seen end-on in Fig. 2) is carried by an arm which arches over M as shown so that all components involved in the positioning of P are out of the way of N, the cassettes and counters. This arm is attached to a shaft Q whose axis is set at the same height as the median height of the X-ray beam. Q can slide axially in its bearings in the channel member U which supports it, and thereby the location of P between M and N can be adjusted. A radius arm R (seen end-on in Fig. 2) is clamped to Q. The far end of R is raised or lowered by a vertically oriented micrometer screw mounted in U. The lever length of R is 0.1 m, so that a 10 μm movement of the micrometer spindle changes the tilt of P by 0.1 mrad. The channel U is itself mounted upon a precision ball-bearing slide W to provide motion transverse to the beam reflected from M. The micrometer screw actuating W has a large thimble permitting easy setting of the mid-beam-height position of P to 1 μm. (These micrometers are not shown in Fig. 2) W is supported by a bracket attached to a standard carrier clamped to the fixed, collimator-carrying arm of the goniometer. This carrier can be attached or removed without disturbing the incident-beam slit assembly or any X-ray shielding arrangements.

3. Outline of the theory.

It is convenient to abbreviate the expression for $S_i/S_r = \sin(θ_M + φ)/\sin(θ_M - φ)$ by the spatial magnification factor $m$. As is well known, the dynamical theory of Bragg reflection by perfect, non-absorbing crystals predicts total reflection over a small angular range: this range in the case of symmetric Bragg reflection (i.e. φ
=0) we denote by $\omega_r$. It is also well known that for perfect, non-absorbing crystals
\[ S_\omega \omega_r = S_\psi_r, \] (1)
$\omega_r$ being the range of angles of incident rays which undergo total reflection and $\omega_r$ the range of angles of rays which have been totally reflected. [The simple relation (1) applies as long as $(\theta_M - \phi)$ is not made so small as to approach the critical angle for total reflection from the crystal surface in the absence of Bragg reflection.] Relation (1) can be understood from conservation of energy, or it can be simply derived by geometric construction in the vicinity of the Lorentz point in reciprocal space; and, as Kuriyama & Boettinger (1976) point out, it can also be obtained by application of the principle of conservation of the component of photon momentum parallel to the crystal surface. From (1) it follows that
\[ \omega_r = m \omega_r = m^{1/2} \omega_r. \] (2)
The significance of (2) in the present technique is as follows. It can be assumed that the monochromator $M$ is operating with a strong reflection, i.e. one with a relatively wide $\omega_r$. The reflection from $N$ may be strong or weak, but if $N$ approaches perfection at all, its angular range of reflection is unlikely to exceed $m^{1/2}$ times that of $M$, given that $m$ is not less than about 20. Hence the beam incident upon $N$, highly collimated though it be, should still comfortably straddle the reflection profile of $N$. Consequently, the diffraction contrast conditions of normal section topographs are reproduced, and their familiar types of image are repeated, but with improved quality. The above statement applies to the dominant, $\sigma$ polarization mode (i.e. the mode with $E$ vector normal to the plane of incidence). If $2\theta_M$ is in the region of 90° then $m^{1/2} \omega_r$ for the $\pi$ component of the reflection from $M$ may not exceed the reflection range of the same polarization component by $N$. But in such circumstances the contribution of the $\pi$ mode to the resultant patterns in $RR'$ and $TT'$ would be unimportant.

The effect of $m$ on the ratio of reflection widths is illustrated by Figs. 3 and 4 which relate to an application of the technique when crystals $M$ and $N$ are both diamond and Cu $K\alpha_1$ radiation is used. The surface of $M$ is (111), the reflection used is 220, giving $m = 22.6$. $N$ is set for the 111 reflection in the Laue case. Structure factors and the Debye-Waller factor for diamond are taken from Dawson (1967). The Bragg-case curve is plotted from equations (16) and (19) of Hirsch & Ramachandran (1950). For the diamond 220 reflection we have assumed the ratio of the two imaginary quantities $F_{\sigma}^2/F_{\pi}^2$ to be 0.9. The Laue-case curve has been simplified to correspond to zero absorption and symmetrical transmission, e.g. equation (91) of Batterman & Cole (1964). Departure from these conditions by $N$ in the experiments performed would not have changed the curve significantly. If both crystals had been symmetrically reflecting, the full width at half maximum of the 220 reflection would have been less than that of the 111 reflection.

It should be noted that even if $M$ were ideally perfect, the insertion of a screen $P$, with means for accurately positioning it, is highly desirable. We take issue with the statement by Boettinger, Burdette & Kuriyama (1979) that 'a single ray of X-rays diffracted by a perfect crystal emerges as a single ray from the entrance point on the surface'. In fact, the Bragg-case Pendellösung interference pattern is present which produces subsidiary maxima, albeit very weak, coming from below the crystal surface. [Here we use Pendellösung in the strict sense, and do not refer to interference between rays reflected from the front and back surfaces of $M$.]
theory of Bragg-case *Pendellösung* fringes has been developed by Uragami (1969) and Kato (1974), and observations of them have been described by Lang & Mai (1979).]

We commence analysis of the joint reflecting behaviour of $M$ and $N$ with Fig. IX-9 and equation (9.51) of Compton & Allison (1935), following the example of Beaumont & Hart (1974). We simplify that equation by neglecting axial divergence, and use it in a modified sense as explained below, appropriate for the case of asymmetric reflection from the first crystal. The intensity reflected by $N$ when rotated by angle $\beta$ from its peak reflecting orientation is

$$P(\beta) = \int \int J(\lambda - \lambda_0)R_M[\alpha - (\lambda - \lambda_0) \tan \theta_M/\lambda_0]$$

$$\times R_N[\pm \beta + \alpha - (\lambda - \lambda_0) \tan \theta_N/\lambda_0] \, d\alpha \, d\lambda, \quad (3)$$

in which the X-ray spectral intensity distribution about a central wavelength $\lambda_0$ (the wavelength of the $K\alpha_1$ peak, say) is $J(\lambda - \lambda_0)$, $R_M(\alpha)$ is the profile of the reflected beam from $M$ (as in Fig. 3, for example), $\alpha$ being a deviation of the reflected beam anticlockwise in Fig. 1, in the direction of increasing reflecting angle from $M$. $R_N$ is the reflection profile of $N$, the sense of $\beta$ is anticlockwise in Fig. 1 for both $(m,n)$ and $(m,-n)$ settings. The upper signs in (3) apply to the $(m,n)$ case and the lower to the $(m,-n)$ case. With profiles as wide as those in Figs. 3 and 4, and with dispersion giving additional substantial contribution to the spread of $P(\beta)$, neglect of axial divergence is just acceptable using crystals only a few millimetres high, well-aligned, and not less than 0.5 m from the focus of a fine-focus X-ray tube. With synchrotron sources this neglect is entirely acceptable. Clearly, if the X-ray spectral distribution is

![Fig. 5. Section topographs through a natural diamond of flattened octahedral habit, thickness 1.56 mm, with the large pair of faces indexed (111) and (1T). The specimen is set with [110] vertical, and the 111 reflection of Cu K\(\alpha_1\) is used. The X-rays enter via the (1T) face which produces the vertical right-hand margin of the image, and they leave through a rounded surface near the [001] apex. Image height 1.95 mm (truncation of top is artificial). Notice stacking-fault images drawn out into horizontal bands; the larger band is 105 \(\mu\)m wide and is centred 0.96 mm above the bottom tip of the image, the upper band is 55 \(\mu\)m wide and is centred 1.38 mm above the bottom tip of the image. (a) Slit-collimated incident beam, 40 kV, 2-8 mA, 19 h exposure. (b) Incident beam collimated by condensing monochromator, arrangement as shown in Fig. 1. When relating the geometry of the image to the geometry of Fig. 1, remember that the specimen is held upside down in Fig. 1, as shown in Fig. 2. 40 kV, 40 mA, 18 h exposure.](image)
ideally sharp, and limits of $\alpha$ are unrestricted, $P(\beta)$ becomes the convolution of $R_M$ and $R_N$. We are here concerned with the bandwidth passed by $M$ and $N$ when $N$ is set for peak reflection. Let $B_{M,N}$ denote this bandwidth in fractional form. If the distance from $N$ to the photographic plate is $L_N$, then the lateral image spread due to $B_{M,N}$ is $L_N B_{M,N} \tan \theta_N$, and this last we desire to minimize. $B_{M,N}$ can be found graphically from DuMond (1937) diagrams, as previously done for multiple, asymmetric reflectors by Nakayama, Hashizume, Miyoshi, Kikuta & Kohra (1973), or derived as follows. Firstly, assume $J(\lambda - \lambda_0)$ is constant over the range of $B_{M,N}$. Substitute

$$\alpha' = \alpha - (\lambda - \lambda_0) \tan \theta_M/\lambda_0$$

in (3), which then gives for $P(0)$

$$P(0) = \int R_M(\alpha') R_N(\alpha') \left( \frac{\alpha' - \alpha}{\alpha' + \alpha} \cos \theta_M + \tan \theta_M \right) \times \left( \frac{\alpha - \alpha_0}{\alpha_0} \right) d\alpha' d\alpha.$$

Equation (4) shows (explicitly, on differentiating both sides with respect to $\lambda$) that the wavelength distribution in the bandwidth $B_{M,N}$ has the shape of the convolution of $R_M$ with $R_N$, and is spread by the scale factor $(\tan \theta_M + \tan \theta_N)^{-1}$. Whether or not in the case of laboratory sources $B_{M,N}$ is usefully narrower than the bandwidth effective in the absence of $M$ depends upon several parameters. It can be so, as discussed in the following section.

### 4. Performance

Fig. 5(a) and (b) shows section topographs of a natural diamond, (a) being taken by the standard technique using beam collimation by narrow slits and (b) by the technique described in this paper. The specimen is a tabular octahedron. It exhibits both internal defects and surface damage. Some surface damage has been removed by etching. Certain severe mechanical damage persists: one example being a crack present in the upper part of the section, which produced intense diffraction contrast (This part is excluded in the fields reproduced in Fig. 5a and b.) The crystal is noteworthy for its small number of dislocations, and even more so for its large grown-in stacking faults. Two large-area stacking faults outcropping on the X-ray entrance surface are intersected by the incident beam in this section. Their fault-fringe images spread out into horizontal bands right across the section topographs since their dynamical images fill the whole energy-flow triangle $OAB$.

Section topographs are usually taken with slit widths ranging between 25 and 10 $\mu$m. One has to see side-by-side the images produced by the wider and narrower slits to appreciate the improvement in resolution effected by use of narrower slits. This is especially true when Cu $K\alpha_1$ radiation is used, with which greater resolution is intrinsically possible than with Mo $K\alpha_1$ and Ag $K\alpha_1$ radiations, and with which Pendellösung fringes are more finely spaced on account of the shorter extinction distances. However, maintaining a mechanical slit of width 10 $\mu$m or less uniform and clean poses constant difficulties under routine laboratory conditions. The most prevalent dust particles appear to be fairly highly absorbing of Cu $K\alpha$ radiation. The bands of reduced intensity crossing the top part of Fig. 5(a) arise mainly from adventitious absorbing matter in the slit system. This problem is avoided in the condensing monochromator method for producing beams of narrow width. The beam leaving the slit used in Fig. 5(a) was 7 $\mu$m wide, measured at the slit exit. In the arrangement used for Fig. 5(b) the calculated beam width $W$, was 8.8 $\mu$m, but the pin $P$ was driven into the beam a little so as to produce a beam whose width recorded just behind $P$ was 7 $\mu$m, giving strict comparability with the conditions used for Fig. 5(a). The latter topograph was taken on a camera set up on a low-power, fine-focus X-ray generator. The goniometer head, with specimen attached, was then transferred to another camera fitted with the accessories described in § 2, which was set up on a high-power X-ray generator. The topographs show that the sections recorded were similarly located in the crystal to within a few micrometres of each other. No difficulty was encountered in this replication, testifying to the convenience of the apparatus used. The monochromator crystal possessed one octahedral face of unusual flatness which was used in its natural state, without polishing or etching. Although it was peppered with percussion damage, there was an area about $2\frac{1}{2}$ mm square which did not include major ring cracks. This area was large enough for the present experiments. Section topograph images obtained with the new technique appeared generally ‘crisper’ than their counterparts taken by the conventional technique. A factor contributing improved clarity (and interpretability) to the images is the suppression of the $\pi$ polarization mode. This gives a Pendellösung fringe pattern of more uniform good visibility in parts of the specimen which taper and in the stacking-fault images, as can be seen by comparing Fig. 5(b) with 5(a). The technique has been applied in a comparison of defect contrast in $RR'$ and $TT'$ images (Mai & Lang, 1980). The symmetry of the ‘bridge’ design was conducive to stability: drifts in the peak of $P(\beta)$ were not more than 1" per day when the apparatus was surrounded by simple draught-excluding shielding.

Fig. 6(a) and (b) shows the measurements of $P(\beta)$ in the $(m, -n)$ and $(m, n)$ settings respectively. (It is no cause for concern that the area above background in Fig. 6b) is 14 times that in Fig. 6(a) because the section through $N$ cut by the incident beam was different in the two settings, with consequent differences in absorption path and intensity contributions from defects such as the stacking faults.) A numerical convolution of the profiles of Figs. 3 and 4 produced a curve whose full width at half-maximum height (FWHM) was 21.6”. Subtracting this from the FWHM values of Fig. 6(a) and (b) gives widths of 18.4 and 56.4" respectively. The ratio of the latter to the former is 3.06, close to the ratio...
\[
(tan \theta_m + tan \theta_n)/(tan \theta_m - tan \theta_n)
= (0.773 + 0.403)/(0.773 - 0.403)
= 3.18,
\]

in accord with the idea that the emission-line profile FWHM and the FWHM of the convolution of \( R_M \) and \( R_N \) combine simply additively to give the rocking-curve FWHM. Using the FWHM of the convolution and the values of \((tan \theta_m \pm tan \theta_n)\) given above we find the FWHM of \( B_{M,N} \) [i.e. the effective \( \Delta \lambda(B)/\lambda_0 \) in the experiments] to be \( 2.84 \times 10^{-4} \) and \( 0.89 \times 10^{-4} \) for the \((m,-n)\) and \((m,n)\) cases, respectively. These figures are to be compared with the values of \( \Delta \lambda(x_1)/\lambda_0 \) for the Cu K\( \alpha_1 \) line where \( \Delta \lambda(x_1) \) is the FWHM of the emission-line profile. Whether we choose an older value of \( \Delta \lambda(x_1)/\lambda_0, 3.8 \times 10^{-4} \) (Compton & Allison, 1935, Table IX-21) or a newer value, \( 2.8 \times 10^{-4} \) (Brogren, 1963), it is evident that in the example cited the \((m,n)\) setting can give a considerable reduction and the \((m,-n)\) setting at least some reduction in image spreading due to dispersion.

5. Applicability to synchrotron radiation sources

We conclude with some proposals for use of the arrangement shown in Fig. 1 with synchrotron radiation. Firstly, we consider section topographs which record sharp, Bragg reflections in the conventional way, then we consider the recording of diffuse reflections by the section topograph method. We advocate setting the planes of incidence and reflection of the \( M, N \) system (i.e. the plane of Fig. 1) at an inclination to the orbit plane of the synchrotron radiation source (SRS). This is to allow \( 2\theta_M \) to take values close to \( 90^\circ \) without total loss in intensity because of the polarization of the source. Of course, setting the plane of Fig. 1 at \( 90^\circ \) to the orbit plane simplifies the X-ray optics, but it is worth noting that the penalty of making this angle as low as 30°, instead of \( 90^\circ \), is only a reduction to one half in the intensity reflected by \( M \) at \( 2\theta_M = 90^\circ \) (assuming \( M \) is perfect and non-absorbing). Setting the plane of Fig. 1 perpendicular to the orbit plane allows an effectively unlimited extension of the beam in the axial direction (i.e. normal to the plane of the figure) and hence permits recording of section topographs with height limited only by the extension of \( M \) in the axial direction. There is freedom to make \( S_y/S_x \) greater or smaller than the values employed in the laboratory experiments reported here. Even if a width of \( S_y \) not lower than 25 \( \mu m \) were needed, and \( m \) is as high as 40, \( S_y \) will still be well within the vertical (i.e. out-of-orbit plane) spread of the beam from the SRS. As regards bandwidth, suppose, for example, that the monochromator setting adopted in the experiments described above was set up at a SRS. The acceptance angle of the monochromator, \( M \), is \( 1/22.6 \) times the FWHM of Fig. 3, and is \( 0.71^\circ \) of arc (0.0034 mrad). Likely magnitudes of the vertical dimensions of the electron beam from the SRS, the distance from tangent point to \( M \), and the width of \( S_y \) suggest cross-fire of about 0.05 mrad in the vertical plane. The latter angle therefore dominates in determining the bandwidth reflected by \( M \), both in the desired reflection and in any harmonics (for which the acceptance angle by \( M \) would be even smaller).

The study of diffuse reflections involves mapping the scattered intensity as a function of position of the scattering vector in reciprocal space, the regions of interest frequently lying close to a reciprocal-lattice point of the ideal crystal (Wooster, 1962). Diffuse reflection topography extends the technique to the mapping of the variation of diffuse reflecting power as a function both of the position of the scattering vector in reciprocal space and of the position of the scattering volume within a crystal specimen that is inhomogeneous as regards degree or type of lattice disorder. When using a source producing characteristic X-rays the experimenter is often severely handicapped by the limited range of orientations of the sections he can cut through reciprocal space in the vicinity of a particular reciprocal-lattice point, given the fixed radius of the Ewald sphere. Moreover, it is often required to analyse the scattering behaviour where scattering power is a rapidly varying function of position of scattering vector
in reciprocal space. The simultaneous functioning of
two Ewald spheres of slightly different radii (cor-
responding to the components of the $\alpha_1\alpha_2$ doublet)
complicates the recording to a degree that is beyond the
scope of any regular deconvolution technique to
unscramble, given the number of experimental para-
eters and low intensities involved. A tunable wave-
length source (covering the range 0.1 to 0.2 nm, say) and
a well-defined bandwidth ($\Delta\lambda/\lambda \approx 10^{-4}$ would be
appropriate) would indeed be a boon. The arrangement
of Fig. 1 could be employed directly, and both $S_i$ and $S_f$
could be scaled up (perhaps tenfold) to provide greater
total flux, the spatial resolution of diffuse reflection
topographs being of necessity limited. However,
weighing against the advantageous simplicity of this
plane monochromator arrangement is its narrow
bandwidth: $\Delta\lambda/\lambda \approx 10^{-4}$ is needlessly small for the great
majority of diffuse reflection studies.

Finally, notice one possibility with systems such as
here discussed when set up at a SRS. If a usefully large
value of $m$ is employed, $\sin(\theta + \phi)$ must also be large,
and the incident beam will pass through the monochro-
mator nearly perpendicularly. The thickness of $M$ need
be no more than a few tens of micrometres, as far as its
Bragg-reflecting properties are concerned. Hence, $M$
can be made as thin as is technically feasible in order to
transmit a high fraction of the X-rays not Bragg
reflected. Accordingly, one may envisage a sequence of
thin, Bragg-reflecting monochromators set up in
tandem on a single beam line, each oriented to operate
with a harder wavelength than its predecessor. If the first one or two monochromators were diamonds, they
would cause negligible loss by absorption and would be
adequate for use with small specimen crystals. The high
stability and thermal conductivity of diamond make it an
ideal choice for insertion into the beam to act as
monochromator. Of course, each monochromator will
transmit a spectrum that is no longer continuous, but,
as seen above, the bandwidths stopped will be so
narrow as to render very unlikely any detriment to
experiments further down the line.

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