Elimination of extrinsic components overlapping lattice distortion variations of a silicon single crystal obtained by double-crystal X-ray topography

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Variations in lattice plane spacing and lattice plane orientation, i.e. $\Delta d/d$ and $\Delta \alpha$, reflect variations in lattice distortion in a single crystal. Double-crystal X-ray topography (DCT) using synchrotron radiation can be used to measure $\Delta d/d$ and $\Delta \alpha$ of a silicon single crystal. However, both $\Delta d/d$ and $\Delta \alpha$ measured using DCT are always overlapped by extrinsic components, showing particular long-range variations. The extrinsic components should be eliminated from the measured $\Delta d/d$ and $\Delta \alpha$ for quantitative characterization of silicon single crystals. A sample-rotation and area-detector traverse (RT) method, applicable to X-ray optics for DCT, has been newly developed. The extrinsic components are eliminated by modification of the intensity distribution on the X-ray topographs using the RT method. From theoretical considerations, it is confirmed that the extrinsic components are mainly due to the $(+,-)$ non-parallel setting between the monochromator and the collimator, and a minute bend in the sample due to its physical restraint.

1. Introduction

To refine silicon devices, it is necessary to know the distribution of impurities, such as interstitial oxygen and substitutional carbon, and that of dopants over a wide region in silicon single crystals. X-ray topography is a useful technique to analyse non-destructively the strain fields of a single crystal. The strain fields can be observed as a textured area in the X-ray topograph, reflecting deviations of a Bragg condition caused by local lattice distortions in the crystal. Local lattice distortions generally induced by impurities and dopants vary by the order of $10^{-8}$, so conventional X-ray topography cannot detect such distortions unless the sample silicon crystal is annealed or is decorated with transition elements in order to enhance the degree of distortion. Double-crystal X-ray topography (DCT) utilizing an asymmetric Bragg reflection has an advantage: it is highly sensitive to minute lattice distortions in as-grown crystals, owing to the narrow angular divergence of the probing X-rays produced by asymmetric reflection. Actually, striation patterns in as-grown magnetic Czochralski (MCZ) silicon can be observed by DCT using synchrotron radiation (SR) and a collimated beam with an asymmetric reflection of Si 800 (Kawado et al., 1991). SR X-rays allow the choice of a wavelength, suitable for reflection, with a large index, which can produce probing X-rays with an angular divergence of the order of $10^{-8}$ rad.

Many reports of the X-ray characterization of single crystals have described the measurement of lattice distortion. Bone (1962) measured the distortion in a germanium crystal using intensity variation on the slope of the X-ray diffraction curve. Imai et al. (1988) measured lattice distortion originating from impurity fluctuations in Czochralski (CZ) silicon. They detected local variations in diffraction intensity by using a counter and a slit, and separated the distortion into variations in lattice plane spacing and lattice plane orientation, i.e. $\Delta d/d$ and $\Delta \alpha$, based on a procedure reported by Kikuta et al. (1966).

In these reports, however, the variation in the intensity of the X-ray topograph was not used to measure the distortion. In our previous work, lattice distortion in an as-grown MCZ silicon crystal was measured using the variation in the optical density of the double-crystal X-ray topograph recorded on a nuclear emulsion plate, where the optical density was digitized by a micro photodensitometer (Kawado et al., 1991). In subsequent DCT experiments, photographic plates were superseded by imaging plates (IP) that allowed us easily to digitize the topograph (Mackay et al., 1993). The IP has an advantage in the quantification characterization of X-ray diffraction intensity on the topograph owing to its wider linear response than that of photographic plate. A system of processing the topographs recorded on IPs was developed for analysing lattice distortion in as-grown silicon crystals (Kudo, Koyima et al., 1994; Kudo, 1994).
Liu et al., 1994), and was successfully used to characterize the imperfections in silicon crystals (Kudo et al., 1997).

Characterization of many silicon crystals revealed that short-range variations (sub-millimetre to a few millimetres order) in lattice distortion were mainly caused by impurities showing growth striations. It also revealed the existence of long-range variations (several tens of millimetres) which overlapped the short-range variations and showed the following tendency: $\Delta d(d)$ gradually shrinks or expands along the direction from the edge to the middle of the sample crystal and $\Delta \alpha$ increases monotonously, implying a concave curve of the sample. It is plausible that the long-range variations reflect extrinsic components independent of the distortions of an individual sample.

We report here a new method using the DCT optics for recording variations in X-ray diffraction intensity caused by rotation of the sample. Intensity variations on a double-crystal X-ray topograph arc processed using an X-ray image produced using the new method before obtaining $\Delta d(d)$ in order to eliminate the extrinsic components. This elimination enables us to obtain accurate $\Delta d(d)$ and $\Delta \alpha$ and to perform precise characterization of the imperfections over a whole sample crystal. Finally, the intensity variations on the topograph are reproduced using the calculation of the diffraction intensity based on a dynamical theory of X-ray diffraction in a perfect single crystal. The calculation confirmed that the extrinsic components are mainly caused by the $\pm$, $\mp$ non-parallel setting between the monochromator and the collimator and the minute bend in the sample due to its being held.

2. Experiment and results

DCT experiments were performed at station BL-1SC in the Photon Factory, Institute of Materials Structure Science, in the High Energy Accelerator Research Organization, using the X-ray optical arrangement shown in Fig. 1. SR X-rays from a bending magnet installed at the beamline were monochromated using a symmetric Bragg reflection of an Si 111 double crystal (monochromator). The monochromated X-rays, having a wavelength of 0.112 nm and a beam size of $2 \times 55$ mm (vertical $\times$ horizontal), were incident on a silicon crystal (collimator) with a glancing angle of 0.84°, satisfying the Bragg condition for an asymmetric Si 800 reflection. Thus the diffracted X-rays from the collimator approximately realized a plane wave of which the sensitivity to the local lattice distortion was of the order of $10^{-7}$.

The monochromator and the collimator were cut (10 mm thick) from (111)-oriented floating-zone (FZ) silicon ingots with a diameter of 100 mm and a resistivity higher than 10,000 $\Omega$ cm. The surfaces of the monochromator and the collimator were polished mechanically and chemically. A sample crystal, about $50 \times 50 \times 10$ mm (length $\times$ width $\times$ thickness), was prepared from a B-doped (100)-oriented as-grown FZ silicon ingot with a diameter of 100 mm. After the sample was etched in order to remove the surface damage due to cutting, the surface, perpendicular to the growth direction [100], was polished, as well as the monochromator and the collimator.

The collimated X-rays illuminated the sample arranged in the (+,−)-parallel double-crystal setting with respect to the collimator. The rocking curve of a symmetric Si 800 Bragg reflection of the sample was measured using a NaI(Tl) scintillation counter. Only X-rays diffracted at the centre of the sample were detected, passing through a slit with an exit of 3 mm$^2$ set between the sample and the counter. An X-ray topograph of the sample was taken on the IP (Fuji DF-UR III) at an angular position where the diffraction intensity decreased to half the maximum of the rocking curve at the lower angle side of its peak. At the angular position, the variation in the diffraction intensity with a rotation of the sample is so sharp that even a minute distortion of the order of $10^{-5}$ produces a clear contrast on the topograph. In addition, an X-ray topograph of the collimator was taken on the IP. The exposure time for both the sample and the collimator was 30 to 60 s using an Al plate of thickness 0.5 mm as an attenuator of the X-rays. All the topographs taken on the IP were digitized by a reader (Joel PXsysTEM) with a pixel size of 50 $\mu$m.

In order to separate the distortion of the sample into $\Delta d(d)$ and $\Delta \alpha$, another topograph of the sample was taken after the sample was rotated 180° around the surface normal (Kudo, Koyima et al., 1994; Kudo et al., 1997).

Fig. 2 shows a double-crystal X-ray topograph of the sample. Good contrast was achieved only in the middle area (1/4 of the whole region), where a spiral striation pattern was clearly visible, showing the distribution of impurities, mainly substitutional carbon atoms.

After the DCT experiments described above, the diffraction X-ray intensity of the sample was recorded by a newly developed method using the same X-ray optics as in the DCT. This method can record only X-rays diffracted from a one-dimensional region of the sample, restricted by a slit between the sample and the IP, and can simultaneously record variations in the X-ray diffraction intensity with a rotation of the sample. First, as shown in Fig. 3, the area of the diffraction X-rays was restricted within a one-dimensional region along the scattering plane formed by the incidence and the emergence vectors of the X-rays. Next, the IP was step-by-step traversed along the direction perpendicular to the scattering plane, synchronized with the rotation of the sample. We refer to this...
novel way of X-ray recording as the sample-rotation and area
detector-traverse (RT) method.

Intensity variations on an X-ray image obtained by the RT
method (RT image) along the scattering plane indicate the
distribution of the diffraction X-rays at each angular position,
and intensity variations along the direction perpendicular to
the scattering plane provide a rocking curve at each spatial
position in the one-dimensional region. In general, an X-ray
topograph gives only information on spatial distribution and a
rocking curve gives only information on angular distribution
of the diffraction intensity. The RT image, however, has the
advantage of giving both these kinds of information, though
the diffraction area is restricted.

Experimental conditions applying when the RT method was
used were set as follows: the slit width was 0.12 mm, the step
of the rotation of the sample was 0.02 arcsec, the range of the
rotation was ±1.5 arcsec around the Bragg peak, wider than
the width of the rocking curve, the step of the traverse of the
IP was 0.06 mm, and the exposure time was 5 s per step
without using the attenuator. The centre of the sample was in

3. Elimination of the extrinsic components
We report here the procedure used to eliminate the extrinsic components using the double-crystal X-ray topograph and the
RT image shown in Figs. 2 and 4.

3.1. One-dimensional variations in lattice distortion
First, intensity profiles $P_{CA}(y)$ and $P_{CB}(y)$ along the
scattering plane in the centre of the topograph were obtained in
case $A$ and $B$, respectively, as shown in Fig. 5, where case $A$
denotes the arrangement of the sample in which the X-rays
illuminated the sample in the upward direction in terms of
Fig. 2, and case $B$ denotes the opposite arrangement after the

![Figure 2](image1)
Figure 2
Double-crystal X-ray topograph of an as-grown FZ silicon crystal. The $Y$
axis is parallel to the vertical direction in Fig. 1 and also to the diametrical
direction of the ingot. The curved top edge of the topograph indicates the
outer edge of the ingot. The dark/light area corresponds to high/low
diffraction intensity.

![Figure 3](image2)
Figure 3
Schematic diagram for the sample-rotation and area-detector-traverse (RT) method.

![Figure 4](image3)
Figure 4
An X-ray image obtained by the RT method (RT image of the sample). The
left and right edges of the image correspond to rotation angles of
$-1.5$ and $1.5$ arcsec relative to the Bragg peak, respectively.

![Figure 5](image4)
Figure 5
Intensity profiles $P_{CA}(y)$ in case $A$ and $P_{CB}(y)$ in case $B$ measured along
the scattering plane on X-ray topographs of the sample. $P_{CA}(y)$ is the
intensity profile obtained from the bottom to the top at the centre of the
topograph shown in Fig. 2. The horizontal axis represents the position on
the topograph along the $Y$ axis in Fig. 2, using pixel numbers.
rotation of the sample by 180° around the surface normal. In particular, the profile $P_{CA}(y)$ was obtained from the topograph shown in Fig. 2. The $X$ and $Y$ axes were determined by pixel lines forming the digitized topograph; in particular, the $Y$ axis was parallel to the scattering plane. As shown in Fig. 5, the intensity distribution is inhomogeneous along the $Y$ axis over the whole sample, as can be seen in the contrasts in the topograph.

In order to determine the angular positions where the topographs giving the profiles $P_{CA}(y)$ and $P_{CB}(y)$ were taken, $P_{CA}(y)$ and $P_{CB}(y)$ were fitted to the intensity distribution along the $Y$ axis on RT images by the least-mean square method, respectively. In case A, line $L_A$ in Fig. 6 is drawn at $x = x_{PA}$, which is the position giving the intensity distribution on the RT image (Fig. 4) fitting to $P_{CA}(y)$. Line $L_d$ is a group of points giving a half maximum at the lower angle side of the rocking curves obtained from the RT image along the $X$ axis. $L_d$ and $L_A$ intersect at point $P_A$ with a $Y$ coordinate of $y_{PA}$. The inclination of $L_d$ gives the rate $r_A$ of the monotonous shift of the rocking curve along the $X$ axis. The shift of the rocking curve is equivalent to the shift of the diffraction area along the $X$ axis. The rotation of the sample, and is considered to reflect the deviations of the Bragg condition along the $X$ axis.

A rocking curve within an angular range corresponding to the sample region along $L_A$ is defined as $RCA(y)$ in case A. The angular range of $RCA(y)$ was determined by converting the length of the sample region into an angle with rate $r_A$ ($3.43 \times 10^6$ pixel rad$^{-1}$). In order to compensate $P_{CA}(y)$ for the angular range, $P_{CA}(y)$ was normalized by $RCA(y)$ and converted into $PC'(y)$, as described below, by using the half maximum point $P_A$ as a base point:

$$PC'(y) = P_{CA}(y)RCA(y_{PA})/RCA(y).$$  \hspace{1cm} (1)

The normalization of $P_{CB}(y)$ was performed in a similar way to case $A$.

Since the collimator and the sample were in a (+,−) parallel setting in this work, the diffraction condition should be satisfied equally at the same relative angular position of the rocking curves. Therefore, intensities of a series of rocking curves obtained from the RT image at the same relative angular position reflect the intensity distribution of the incident X-rays along the scattering plane. Intensity profile $P_{PA}(y)$ was obtained at the peaks, $L_p$ in Fig. 6, of the series of rocking curves. Normalization of $PC'(y)$ by $P_{PA}(y)$ was performed to compensate for the intensity distribution of the incident X-rays on the basis of the following equation:

$$PC''(y) = PC'(y)P_{PA}(y_{PA})/P_{PA}(y).$$  \hspace{1cm} (2)

Similarly, normalization was performed in case B. Normalized $PC'(y)$ and $PC''(y)$, i.e. $PC''(y)$ and $PC''(y)$, shown in Fig. 7, are the intensity profiles which no longer include external factors, and so can be used to calculate $\Delta d/d$ and $\Delta \alpha$, as follows:

$$\Delta d/d(y) = \frac{k_y[PC''(y) - PC''(y)]}{PC''(y)} - \frac{k_y[PC''(y)]}{PC''(y)};$$  \hspace{1cm} (3)

and

$$\Delta \alpha(y) = \frac{k_y[PC''(y) - PC''(y)]}{PC''(y)};$$  \hspace{1cm} (4)

where $\theta$ is the Bragg angle of Si 800 (55.6° in this work), $k$ is the slope of the rocking curve, subscript letters ($A$ and $B$) indicate each case, and $y_i$ is the initial point (bottom in Fig. 2).

Profiles of $\Delta d/d$ and $\Delta \alpha$ calculated using equations (3) and (4) are shown in Fig. 8(a). For comparison, profiles of $\Delta d/d$ and $\Delta \alpha$ calculated using the original intensity profiles $P_{CA}(y)$ and $P_{CB}(y)$ instead of $PC''(y)$ and $PC''(y)$ are shown in Fig. 8(b). It was found by equations (3) and (4) that in Fig. 8(b), $\Delta d/d$ showed a concave profile because of a slight concave tendency of both $P_{CA}(y)$ and $P_{CB}(y)$ and, on the other hand, $\Delta \alpha$ showed a tendency to increase monotonously because of both the tendency to increase in $P_{CA}(y)$ and to decrease in $P_{CB}(y)$. As shown in Fig. 8(a), the modification of intensity distribution on the basis of equations (1) and (2) in case $A$, $PC'(y)$ was obtained in a similar way to case $A$.

![Figure 6](image)

Figure 6
Lines $L_d$ and $L_A$ showing where the intensity becomes half maximum at the lower angle side and at the higher angle side of each rocking curve obtained from the RT image along the $X$ axis shown in Fig. 4, respectively; $L_p$ shows the position of the peak of the rocking curve. Line $L_d$: position giving the intensity profile fitted to $P_{CA}(y)$ shown in Fig. 5. Point $P_A (x_{PA}, y_{PA})$: intersection of $L_d$ and $L_A$.

![Figure 7](image)

Figure 7
Intensity profile $PC''(y)$ given by modifying $P_{CA}(y)$ on the basis of equations (1) and (2) in case $A$. $PC''(y)$ was obtained in a similar way to case $A$. 

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where $P_{C_A}(x,y)$ is the original intensity on the topograph shown in Fig. 2, $P'_{C_A}(x,y)$ is the intensity finally obtained by the modification, and $x_{PA}$ and $y_{PA}$ are $X$ and $Y$ coordinates of point $P_A$ in Fig. 6, respectively.

$\Delta d/d$ and $\Delta \alpha$ free from the extrinsic components can be calculated in two dimensions using the following equations, similar to equations (3) and (4):

$$\Delta d/d(x,y) = [k_P[P_{C_A}(x,y) - P_{C_A}(x_0,y_0)] + k_A[P_{C_B}(x,y) - P_{C_B}(x_0,y_0)]]/2k_Ak_B \tan \theta$$

and

$$\Delta \alpha(x,y) = [k_P[P_{C_A}(x,y) - P_{C_A}(x_0,y_0)] - k_A[P_{C_B}(x,y) - P_{C_B}(x_0,y_0)]]/2k_Ak_B,$$

where $x_0$ and $y_0$ are the $X$ and $Y$ coordinates of the base point for the variations in lattice distortion, respectively. Figs. 9(a) and 9(b) are images showing $\Delta d/d$ and $\Delta \alpha$ in the whole sample, respectively, calculated using equations (7) and (8).

3.2. Two-dimensional variations in lattice distortion

At the beamline used in this work, spatial and vertical angular distributions of synchrotron radiation are uniform along the horizontal direction parallel to the orbital plane of the storage ring. In addition, the tilt of the sample was fully adjusted for the incident X-rays because the contrast on the topograph shown in Fig. 2 is homogeneous, except for the striation pattern, along the X-axis direction equivalent to the horizontal direction. Therefore, using a procedure similar to the one-dimensional case in the preceding section, the intensity distribution on the topograph of the sample can be modified, and images showing variations in lattice distortion can be obtained by using the modified intensity distribution.

In order to expand the region of intensity distribution to be modified from one dimension to two dimensions, the following equations were used in case A, instead of equations (1) and (2):

$$P'_{C_A}(x,y) = P_{C_A}(x,y)R_{C_A}(x_{PA},y_{PA})/R_{C_A}(x_{PA},y)$$

and

$$P'_{C_B}(x,y) = P_{C_B}(x,y)P_{PA}(x_{PA},y_{PA})/P_{PA}(x_{PA},y).$$

Figure 9: Images of $\Delta d/d$ (a) and $\Delta \alpha$ (b) obtained by modified topographs. Contrast was adjusted in the range $-1.8 \times 10^{-7}$ to $2.2 \times 10^{-7}$ in $\Delta d/d$ and $-2.0 \times 10^{-7}$ to $0.9 \times 10^{-7}$ in $\Delta \alpha$. Higher values are in the dark area in both $\Delta d/d$ and $\Delta \alpha$.
where the base point was set at the centre of the sample. Anomalous local variations in $\Delta \theta$ and $\Delta x$ around the bottom left corner and near the right edge in Fig. 9 are considered to be due to the beeswax used for attaching the sample.

As shown in Fig. 9, $\Delta \theta$ slowly increases from each striation to the next outer one and then abruptly decreases, i.e., $\Delta \theta$ shows a saw-edged variation. On the other hand, $\Delta x$ is nearly uniform between each striation, and is lower at each striation than in the area adjacent to the striation, i.e., $\Delta x$ shows a pulsed variation. It is reasonable that $\Delta \theta$ showing the striation pattern causes $\Delta x$ since the differentiation of the saw-edged variations produces the pulsed variations. The elimination of the extrinsic components from $\Delta \theta$ and $\Delta x$ in two dimensions enables us to characterize the whole sample crystal precisely.

4. Discussion

A calculation on the basis of the dynamical theory of X-ray diffraction in perfect single crystals is useful for understanding variations in the diffraction intensity from silicon single crystals (Ishikawa & Kohra, 1991). A ray-tracing procedure applicable to the calculation can give us information on the distribution of the diffraction intensity on the imaging plane where topographs are taken. Therefore, a ray-tracing calculation using our original program was performed under the experimental conditions of DCT using SR in order to investigate the origin of the extrinsic components overlapping variations in lattice distortion.

First, the intensity distribution of X-rays incident to the sample, i.e., X-rays diffracted from the collimator, was calculated along the scattering plane, as shown in Fig. 10. The calculated distribution was obtained under the assumption that all the silicon crystals aligned in the X-ray optics were free from distortion, i.e., thermal deformation of the first crystal of the monochromator due to illumination by SR, and bending of the silicon crystal due to its being held were negligible. The calculated profile reproduced the measured profile well. In the X-ray optics in this work, the angular divergence of SR is kept as it is by diffraction at the monochromator and is much larger than the viewing angle of the collimator from the SR source. Therefore, the diffraction at the collimator mainly determines the intensity distribution, which is similar to a Gaussian distribution, owing to the (+,−) non-parallel setting between the monochromator and the collimator. Neither the angular divergence of SR nor the diffraction at the monochromator has an effect on the distribution. The width of the distribution can be changed by varying the offset angle between the first and the second crystal of the monochromator.

On the other hand, it was observed from the RT image of the sample (Fig. 4) that the distribution of the diffraction intensity of the sample was shifted along the scattering plane, changing its shape with a rotation of the sample, as shown in Fig. 11(a). As shown in Fig. 11(b), the distribution of the diffraction intensity of the sample was calculated under the assumption that all the silicon crystals, including the sample in the optics, were free from deformation and bending; this assumption was also made for the calculation on the collimator. These calculated profiles are quite different from the experimental results shown in Fig. 11(a) with regard to shape, width and intensity variations with a rotation of the sample.

The intensity of the calculated profiles was changed by a rotation reflecting the width of a rocking curve of 1 arcsec. In general, the distribution of the diffraction intensity of the sample can be expected to be homogeneous if it is a perfect crystal. However, the calculation revealed that the distribution of the diffraction intensity of a sample can be inhomogeneous even if it is a perfect crystal. The inhomogeneous distribution can result in extrinsic components overlapping variations in lattice distortion in the sample. The calculated profiles show almost the same distribution as the diffraction intensity of the collimator (Fig. 10) owing to the (+,−) parallel setting between the collimator and the sample. Consequently, the modification of the intensity distribution on the basis of equations (2) or (6) in §3 is equivalent to the elimination of the extrinsic component due to the (+,−) non-parallel setting between the monochromator and the collimator, which causes the inhomogeneous distribution of X-rays incident to the sample.

Finally, the experimental distribution was successfully reproduced, as shown in Fig. 11(c), by calculation assuming that the sample was slightly and homogeneously bent and that the bend caused an increase in the inclination of the lattice planes along the scattering plane at a rate $\gamma$ equivalent to the rate $\gamma^2$ in §3.1. In addition, the calculation was performed under the same conditions as the calculation on the collimator shown in Fig. 10. The radius of curvature of the bend was estimated to be about 21 km by the rate $\gamma^2$ (4.81 $\times$ 10$^{-8}$ rad mm$^{-1}$). Because such a small bend is often detected for silicon crystals other than the sample in this work (Kudo et al., 1997), it is reasonable to conclude that the bend of the sample was caused by its being held, as described in §3. Therefore, it was confirmed by the calculation of the profiles shown in Fig. 11(c) that the modification of the intensity distribution on the basis of equations (1) or (5) in §3 is

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**Figure 10**

Calculated intensity profile (smooth curve) fitted to a profile (irregular curve) measured along the scattering plane on topograph of the collimator. The horizontal axis represents positions along the scattering plane on the topograph, the centre of which is the origin. Abrupt increases in intensity on the left and right side of the measured profile indicate the bottom edge (closer to the synchrotron radiation source) and the top edge of the collimator, respectively.

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Y. Kudo et al. - X-ray topography
equivalent to the elimination of the extrinsic component caused by the bend of the sample due to its being held.

5. Conclusions

DCT using SR can be used to obtain \(\Delta d/d\) and \(\Delta \alpha\) of as-grown silicon single crystals as variations in lattice distortion. However, it was found from characterization of many silicon crystals that extrinsic components showing particular long-range variations always overlap both \(\Delta d/d\) and \(\Delta \alpha\) measured as a function of position on the crystal. The extrinsic components show shrinkage or expansion in \(\Delta d/d\) from the edge to the middle of a sample crystal and a monotonous increase in \(\Delta \alpha\) over the whole crystal. Because the extrinsic components can be dominant in measured \(\Delta d/d\) and \(\Delta \alpha\), it is essential to eliminate the extrinsic components to characterize quantitatively silicon single crystals using \(\Delta d/d\) and \(\Delta \alpha\).

We have developed a new method, called the RT method, for recording the diffraction intensity of a sample in DCT optics. The RT method can record only X-rays diffracted from a one-dimensional region of a sample on an IP, which is step-by-step traversed and synchronized with the rotation of the sample. The intensity variation on an X-ray image obtained by the RT method (RT image) along the direction perpendicular to the one-dimensional region provides a rocking curve at each spatial position in the one-dimensional region on the sample.

Intensity distributions on X-ray topographs of an as-grown E1 silicon crystal used as a sample were modified on the basis of the RT image in order to eliminate the influence of deviations of the Bragg condition on the sample and the inhomogeneous distribution of incident X-rays. The extrinsic components were eliminated from \(\Delta d/d\) and \(\Delta \alpha\) obtained using the modified intensity distribution. From theoretical investigation, we confirmed that the extrinsic components are mainly due to the \((\pm \pm)\) non-parallel setting between the monochromator and the collimator and the minute bend in the sample due to its being held.

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