LARGE-AREA X-RAY TOPOGRAPHY TO OBSERVE 300-MM-DIAMETER SILICON CRYSTALS

The manufacturing of 300-mm-diameter silicon wafers, now used as substrates for the ULSI fabrication, requires development of large-area X-ray diffraction topography with high strain-sensitivity to detect crystal imperfections. Such irregularities, *e.g.* growth striations, and surface damage may adversely affect the electrical characteristics of ULSI. Recently, we have created an experimental apparatus designed to acquire large-area topographs of silicon crystals at the second experimental hutch of beamline **BL20B2**; the set up includes the use of a horizontally-wide and monochromatic X-ray beam made possible by 200 m distance between the hutch and the bending-magnet source point [1].

Using this apparatus, we observed surface damage resulting from slicing and polishing, comparing the topographic images taken using low- (8.7 keV), medium- (21 keV) and high- (60 keV) energies X-rays [2, 3]. The p-type CZ silicon crystals used were 300-mm in diameter and 10 mm-thick with a [100] surface orientation. After slicing with a wire saw, the crystal surface was etched slightly, lapped, and then polished both mechanically and chemically.

A schematic diagram of the experimental arrangement includes a 300-mm-wide X-ray beam, monochromatized by the Si (311) double-crystal monochromator in the optics hutch (Fig. 1). This beam was incident on the sample crystal that was set on the sample stage of the horizontal-axis precision goniometer of a tangential-bar type, at a glancing angle less than 1 degree. The energy of the X-ray beam was tuned to either 8.7, 21, 57 or 60 keV by operating the double-crystal monochromator in order to acquire topographs using asymmetric reflections of 311, 511, 12 2 2 and 911.

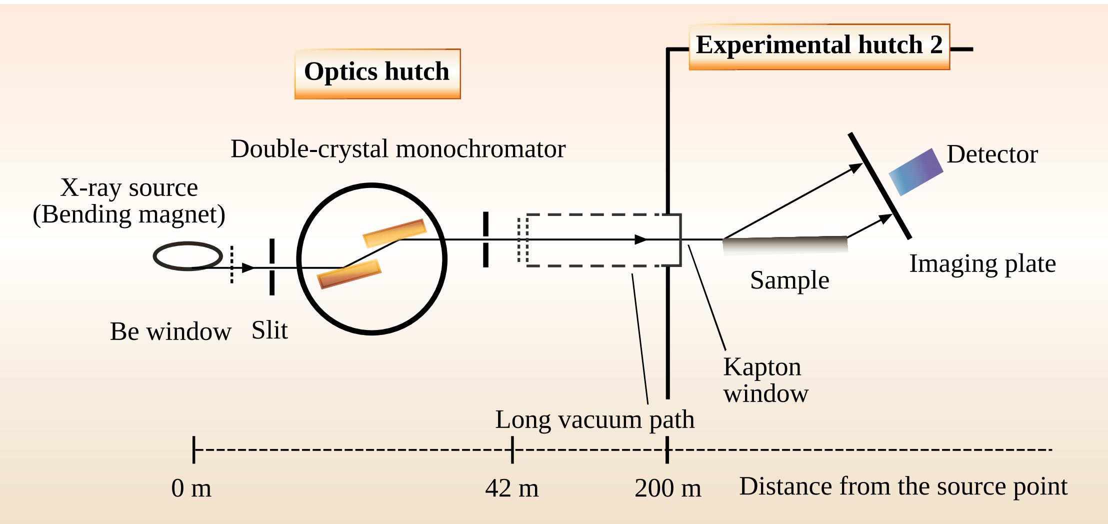

Fig. 1. Schematic diagram of the optical system for large-area X-ray diffraction topography. The 300 mm- wide and monochromatic X-ray beam, obtained at the 200 m point apart from the bending-magnet source, was used to acquire topographs of a 300-mm-diameter silicon crystal sample.

Rocking curves were calculated for the asymmetric 311, 511 and 911 reflections at a fixed glancing angle of 1 degree on the basis of the dynamical theory of X-ray diffraction (Fig. 2). The maximum values of the gradient at the low-angle side of the curves are 0.148, 0.761 and 4.552 $arcsec^{-1}$ for the 311, 511 and 911 reflections, respectively. The curve for the asymmetric 12 2 2 reflection was similar to that for the asymmetric 911 reflection. These results indicate that use of the higher-order asymmetric reflection of higher-energy X-rays improves the strain sensitivity, when the topographs are taken at the angle position of half-peak intensity.

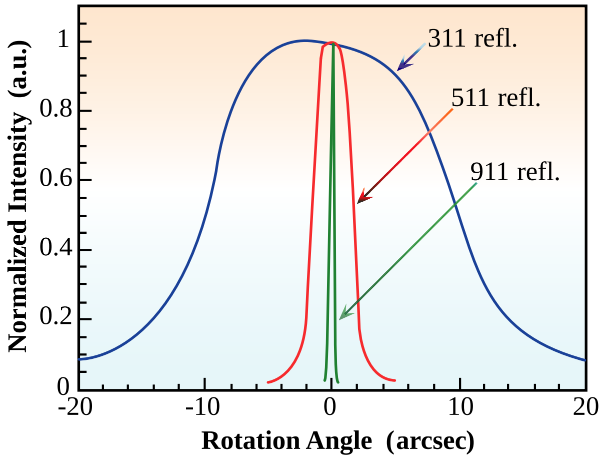

Fig. 2. Calculated rocking curves from (100) silicon. Incident angle was fixed at 1 degree; the asymmetric 311, 511 and 911 reflections used 8.7, 21 and 60 keV X-rays, respectively.

Topographs, recorded on an imaging plate (IP) with a pixel size of 100 μm^2, were reconstructed with an IP reader. The two topographs of a sliced and slightly etched sample (Fig. 3a and b) were taken using the asymmetric 511 reflection of 21 keV X-rays at the lower angle side and at the higher angle side of the rocking curve; modification by image processing then created a circular sample shape. Long line images with equal intervals were identified as saw marks caused by slicing. The reversal of image contrast within the same areas of the two topographs demonstrates the presence of minute and wide strain-fields in the surface region of the sample.

Using the asymmetric 12 2 2 reflection of 60 keV X-rays with higher strain-sensitivity, we examined minute residual damage caused by polishing. Circular defect patterns and microscratch images (Fig. 4) were observed; this detection method allowed the improvement of current polishing procedures.

The use of extremely asymmetric reflections of a

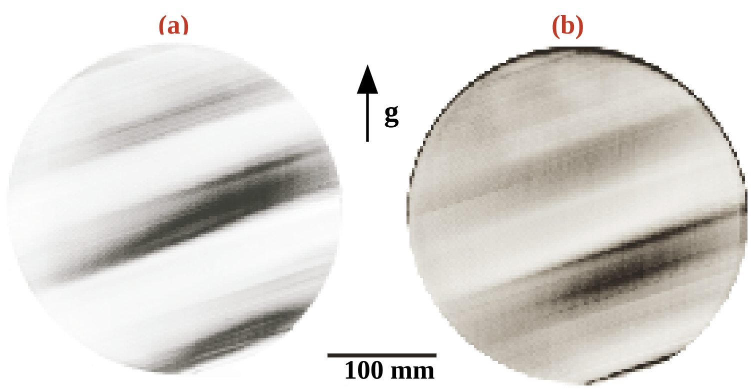

*Fig. 3. X-ray topographs of a 300-mm-diameter CZ silicon crystal after slicing, followed by slight etching. (**a**) and (**b**) were taken using the asymmetric 511 reflection of 21 keV X-rays at the low-angle side and the high-angle side of the rocking curve, respectively. The arrow designates the diffraction vector **g**.*

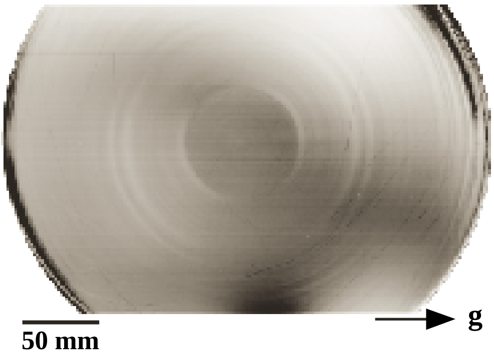

*Fig. 4. X-ray topograph taken with the asymmetric 12 2 2 reflection of 60 keV X-rays after a polishing test. Circular patterns were identified as surface damage caused by polishing. The arrow designates the diffraction vector **g**.*

300-mm-wide and monochromatic X-ray beam enables the acquisition of X-ray topographs all over a 300-mm-diameter silicon crystal, using only a single X-rays exposure. This technique will be useful in clarifying impurity inhomogeneity, dubbed growth striations, within 300-mm-diameter CZ silicon crystals.

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