BL24XU
Hyogo ID

1. Introduction

BL24XU is known as the Hyogo ID beamline. It is a contract beamline designed by Hyogo prefecture for industrial applications. BL24XU is a branched beamline employing a figure-8 undulator light source, a diamond (220) beam-splitting monochromator for branched line A, and a Si (111) double-crystal monochromator (DCM) for mainstream B. The end-station is specialized for high-resolution structural characterization by microbeams and imaging (Table 1).

Recently, we have begun actively promoting the use of data-driven science and engineering such as applying machine learning to analysis utilizing synchrotron radiation. The informatics approach has the potential to rapidly derive the relationship among the structure, physical properties, and manufacturing processes by analyzing a number of specimens under different conditions. In addition, it may extract useful features from massive amounts of data, such as two-dimensional spectrum mappings.

Efforts continue in the development of new measurement methods. Bright-field X-ray topography, which was developed in recent years, is now available to industrial users. Here, we report its developments.

Table 1. Specifications of the measurement techniques in BL24XU.

Measurement techniques	Structural information	Spatial resolution
Projection / imaging microscope / coherent diffraction CT	2D/3D image Field of view: 1 μm–1 mm Absorption, refraction contrast (projection / imaging microscope) Absorption, phase contrast (coherent diffraction)	10 nm–0.33 μm
Microbeam SAXS / WAXD / XRF	Periodic / aggregation structures from angstrom-scale to several hundred nm in size Distribution of crystal grains Elemental mapping	0.5–5 μm
Bonse–Hart USAXS	Periodic / aggregation structures 16 nm–6.5 μm in size	Bulk
Highly parallel microfocus diffraction, bright-field topography	Local strain, dislocation	0.5–30 μm (diffraction), 0.65 μm (topography)
Near-ambient-pressure HAXPES	Chemical state	30 μm

2. Bright-field X-ray topography under the super-Borrmann condition

X-ray topography exerting the super-Borrmann effect has been performed to display the dislocation images using synchrotron radiation with a high-speed and high-resolution CMOS camera [1]. To obtain X-ray topographs with minimized image deformation, we employed forward-transmitted (but refracted) X-rays that satisfied the Bragg conditions for the two $\{111\}$ adjacent planes lying symmetrically with respect to the {100} plane of symmetry, as demonstrated in Fig. 1.

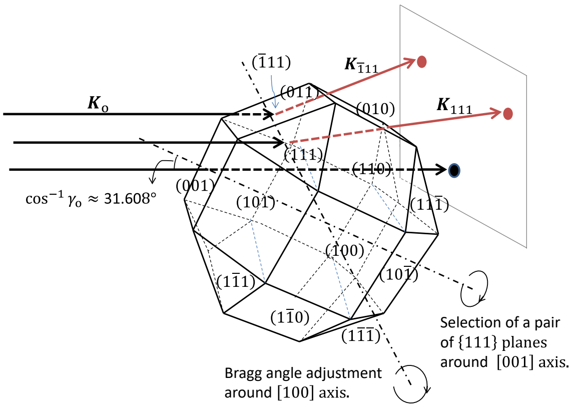

Fig. 1. Incident X-rays $\boldsymbol{K}_o$ and reflected X-rays $\boldsymbol{K}_{111}$ and $\boldsymbol{K}_{\bar{1}11}$ simultaneously satisfying Bragg conditions for 111 and $\bar{1}11$ reflections, respectively. Sample rotations around [001] and [100] are performed, respectively, to select a pair of {111} planes and for Bragg condition adjustment to satisfy the individual three-beam diffraction condition.

The X-ray energy in the present experimental case of using synchrotron radiation was $E = 10\ \text{keV}$ and the Ge slab thickness was $t = 0.05\ \text{cm}$ with the (100) entrance surface. Before the experiment, the minimum attenuation coefficients for σ and π polarizations of the incident X-rays in the three-beam case, A^{σ}_{min} and A^{π}_{min} respectively, are calculated. Results demonstrate that A^{σ}_{min} and A^{π}_{min} are almost 20 times larger than those in the two-beam (usual Borrmann effect) case. Figure 2 shows fluorescent spots of (a) the directly transmitted X-ray beam denoted as "0", (b) the direct beam and the 111-reflected beam, and (c) the direct beam, the 111-reflected beam, and the $\bar{1}11$-reflected beam. It can be easily noted that the triple fluorescent spots in Fig. 2(c) are much brighter than those in Fig. 2(b), which indicates the super-Borrmann effect.

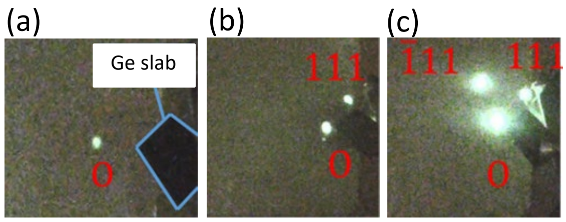

Fig. 2. Reflection spots on a fluorescent sheet. (a) Directly transmitted X-ray beam denoted as "0", (b) direct beam and 111-reflected beam (suggesting usual Borrmann case) and (c) direct beam and 111- and $\bar{1}11$-reflected beams (suggesting the super-Borrmann case).

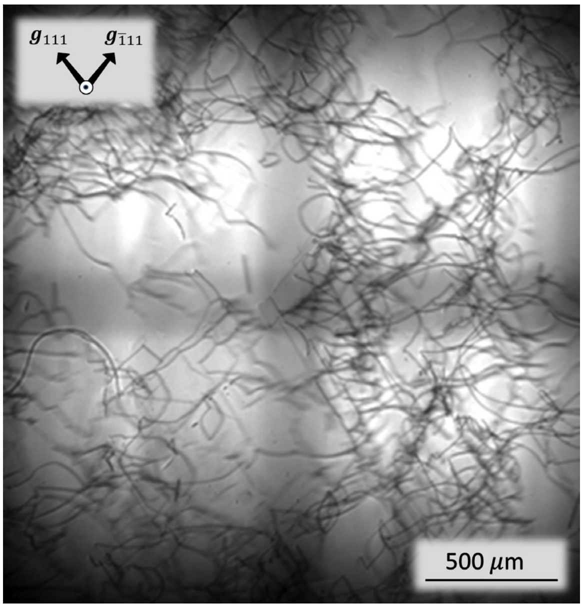

Fig. 3. X-ray topograph of a germanium slab taken by simultaneous 111 and $\bar{1}11$ reflections without deformation correction. Four images are pasted together to obtain a wide-area topograph.

Figure 3 shows one of the topographs taken under the super-Borrmann conditions shown in Fig. 2(c) using a pair of 111 and $\bar{1}11$ reflections without deformation correction. Considering the X-ray source is approximately $1.2 \times 1.2\ \text{mm}^2$ in size, four topographic images are pasted together to achieve a wide-area topograph.

Forward-transmitted X-rays using synchrotron radiation were found to be effective for topographs not only under the usual multiple diffraction conditions but also under the super-Borrmann conditions.

Regarding the operation of the experimental stations for user access, we would like to express our gratitude for the cooperation of JASRI.

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Reference:

[1] Matsui, J. Takatsu, K. & Tsusaka, Y. (2022). *J. Synchrotron Rad.* **29**, 1251–1257