BL16B2
SUNBEAM BM

1. Introduction

BL16B2, which is a SUNBEAM BM beamline, together with its sister beamline BL16XU, was built to develop various industrial materials by utilizing the high-brightness beam at the large-scale synchrotron radiation facility in SPring-8. It is utilized and operated by the SUNBEAM Consortium, a private organization composed of 13 companies* (12 firms and one electric power group). BL16B2 began operations in September 1999, and the beamline use contract was renewed in April 2018. In August 2020, we received an interim evaluation and obtained a "continuation" evaluation result.

X-rays emitted from a bending magnet are monochromatized, shaped, and converged in an optics hutch. The experimental hutch contains a diffractometer and a multipurpose experimental table for XAFS and imaging measurements. Figure 1 and Table 1 show a schematic and the characteristics of BL16B2, respectively.

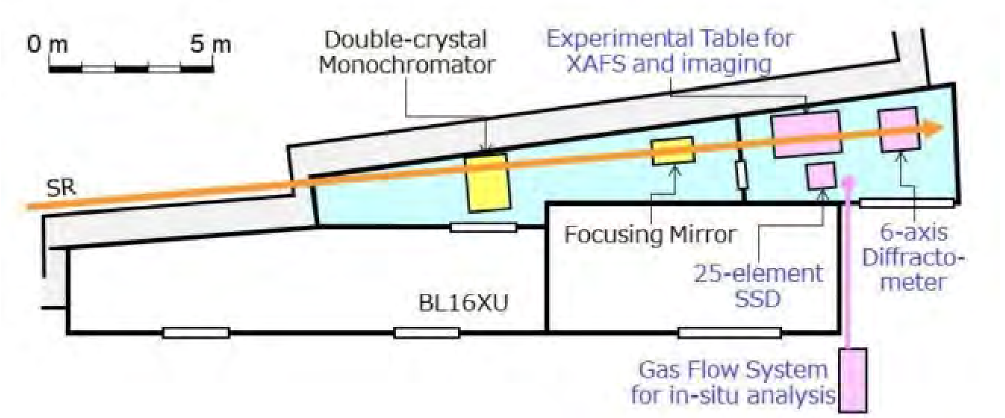


Fig. 1. Outline of BL16B2.

Table 1. Characteristics of BL16B2.

Light source	Bending magnet
Energy range	4.5–113 keV
Energy resolution (ΔE/E)	~10^{-4}
Photon intensity, beam size	~10^{10} photons/s <60 mm (H) × 5 mm (V) without focusing mirror <0.1 mm (H) × 0.1 mm (V) with focusing mirror
Experimental facilities	XAFS, Topography, Imaging, XRD, Gas flow system (corrosive or toxic gas is possible)

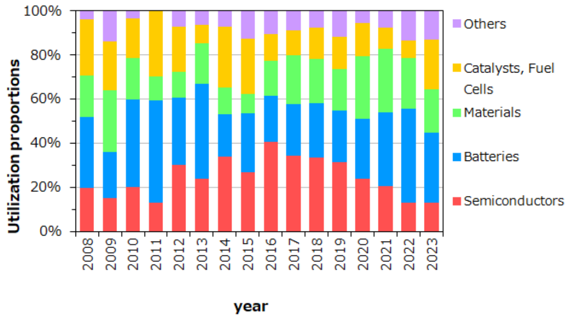
*Kawasaki Heavy Industry, Ltd., Kobe Steel, Ltd., Sumitomo Electric Industries, Ltd., Sony Group Corp., Electric power group (Kansai Electric Power Co., Inc., Central Research Institute of Electric Power Industry), Toshiba Corp., Toyota Central R&D Labs., Inc., Nichia Corp., Nissan Motor Co., Ltd., Panasonic Holding Corp., Hitachi, Ltd., Fujitsu Ltd., Mitsubishi Electric Corp.

2. Utilization

Figure 2 shows the past 15 years of changes by application field and by measurement method for each company's research projects conducted at BL16B2. The vertical axes are the percentage of total utilization time allocated to each company for each year when the adjustment time and study time were not included.

By application field, the semiconductor, battery, and material fields are the three main fields where the use of semiconductors is on the decline and the use of batteries (including catalysts and fuel cells) is on the rise.

By measurement method, XAFS accounted for 60% or more for almost all years, indicating that XAFS was used in a wide range of fields. On the other hand, the use of imaging and topography was also found to be on the rise. This was likely due to the introduction of noise-free X-ray imaging in FY2018, which has seen increased use within the community.



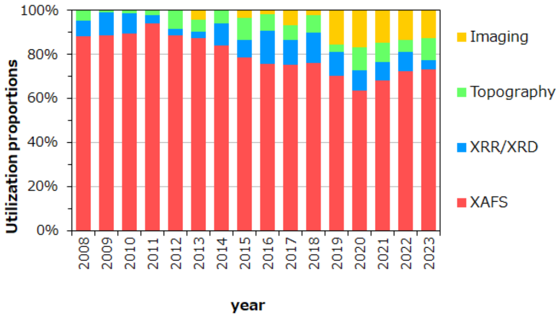


Fig. 2. Relative utilization times of BL16B2 in the past decade.

3. Topics in FY2023

Below, the research and upgrades conducted in FY2023 are described.

3-1. The launch and results of trial observations of refraction-contrast phase imaging at SUNBEAM

This time, for the purpose of highly sensitive nondestructive three-dimensional observations of composite materials and organic materials, the diffraction enhanced imaging (DEI) method has been launched. It provides a good balance between density resolution and dynamic range, and makes it relatively easy to produce high-energy X-rays [1].

As shown in Fig. 3, DEI uses X-ray diffraction to detect the refraction angle of X-rays ($\Delta\theta \propto$ partial derivative of the phase shift) with a single crystal (hereinafter referred to as the "analyzer crystal") installed downstream of the subject. When the incident angle of the analyzer crystal

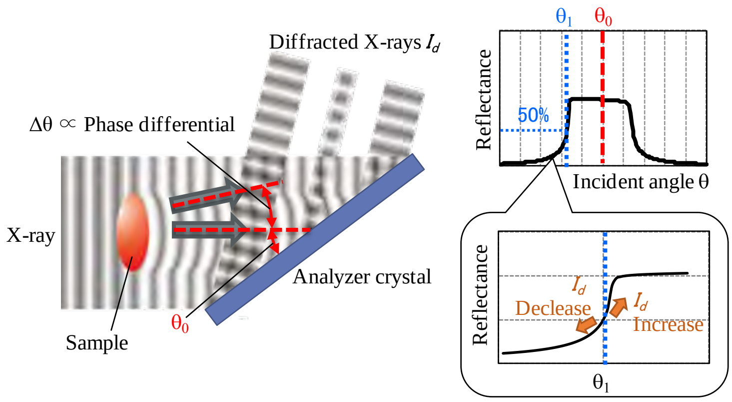


Fig. 3. Principle of diffraction-enhanced X-ray imaging (DEI).

shifts slightly from the Bragg angle (θ0) to the lower angle side and the angle (θ1) at which the intensity of the diffracted X-rays (Id) becomes approximately half, the intensity of the diffracted X-rays increases when Δθ is refracted to the higher angle side or decreases when refracted to the lower angle side. By applying this principle, the analyzer crystal is angle-scanned at around the Bragg angle, and the phase differential image is obtained by calculating the center angle of the diffraction intensity curve (locking curve) for each pixel for the group of obtained multiple diffraction images.

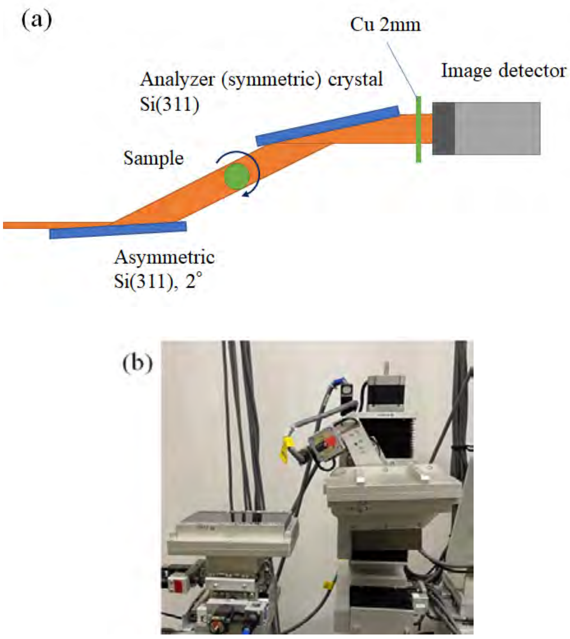


Fig. 4. (a) Schematic diagram and (b) photograph of the DEI system built at BL16B2.

Figure 4(a) shows a schematic diagram of the DEI system built on the XAFS surface plate of BL16B2 based on the same principle, and Figure 4(b) shows a photograph. At this beamline, the vertical width of the incident X-ray beam is only a few millimeters, and an asymmetric crystal (Si[311] degree of asymmetry of 2°) is installed upstream to expand the beam vertically by a factor of three (at 72 keV). In addition, the large-field, high-sensitivity image detector (Andor Zyla 5.5 HF, fiber-coupling type with a magnification of 1×, pixel size of 6.5 mm, 2560 × 2160 pixels, field of view of 16 × 13 mm^2), which was introduced when the equipment was updated in 2017 by the Sunbeam Community, was used to detect the diffraction X-ray image. To control each device (such as the motor controller and image detector) and to make measurements by DEI, the control software CTRL-7, which was based on the data karte system (SAGA light source data karte system: SAKAS) developed at the Kyushu Synchrotron Light Research Center (SAGA Light Source) was used [2]. Note that when using this system, the Si(311) system (25 keV or more) and the Si(111) system (25 keV or less) can be switched in accordance with the energy of the X-rays used.

Figure 5(a) shows the observation results (cross-sectional images) of a BNC cable obtained using the above system (Si[311] system). The X-ray energy is 72 keV, the exposure time for each diffraction image is 1 s, the number of points of the rocking curve (angle- scanning of the analyzer crystal) is 21, and the number of projections in the CT is 500 per 360 degrees. In addition, Figure 5(b) shows the result of the observation of the same sample obtained using normal absorption contrast X-ray CT with the DEI crystal optical system away from the optical axis.

In Figure 5(a), the high sensitivity of the phase contrast makes it possible to visualize not only the signal line and ground mesh copper wire (metallic material) in the center but also other organic materials, including the insulator between the signal line and ground, and the cable jacket (cable protection material). On the other hand, in Figure 5(b), organic materials are not visible, and only the signal line and ground mesh, which are both made of copper wire, are visible owing to a high X-ray energy of 72 keV.

In addition to the above, trial imaging of plants and other subjects was conducted using a Si(111) system as the crystal optical system. A variety of high-resolution three-dimensional images were successfully obtained.

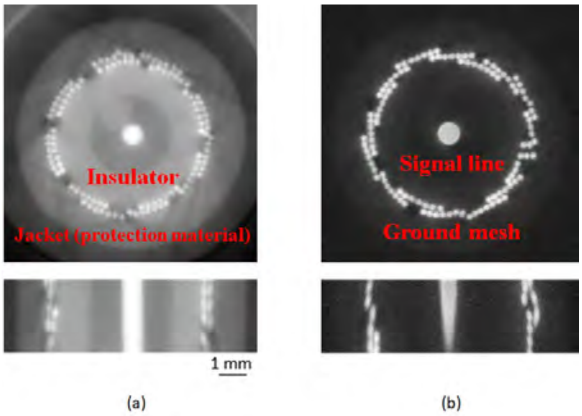


Fig. 5. Observation results of BNC cable (energy: 72 keV): (a) DEI image, (b) normal CT image.

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References:

[1] D. Takamatsu, *SUNBEAM Annual Report with Research Results, Part 1*, 19 (2023).

[2] A. Yoneyama et al., *AIP Conference Proceedings*, 2990 (2023).