

BL28B2

White Beam X-ray Diffraction

1. Introduction

BL28B2 is dedicated to multiple techniques using white X-rays in various research fields. It is a bending magnet beamline that provides white X-rays from a bending magnet source without passing through any optical devices. The techniques involve X-ray diffraction, X-ray microtomography (micro-CT), and ultrafast X-ray radiography. Thus, the beamline supports various experiments such as the evaluation of structure materials using white X-ray diffraction and the three-dimensional observation of metallic objects and highly dense materials such as fossils and concrete using high-energy X-ray micro-CT. Moreover, an automatic X-ray micro-CT system is in operation. To improve and upgrade the measurement techniques using this beamline, the research and development of experimental techniques and instruments was conducted in FY2024.

2. Upgrades of measurement techniques and instruments

2-1. X-ray diffraction

The key feature of the diffraction experiments conducted at BL28B2 is the use of white X-rays. Energy-dispersive X-ray diffraction experiments, Laue pattern measurements, and white X-ray topography are performed using a white beam diffractometer system.

Figure 1 shows the layout and a photograph of the energy-dispersive diffraction experimental setup. The white X-ray beam, shaped by the incident slit S1, irradiates the sample. The energy of the diffracted X-rays that pass through the receiving

slits S2 and S3 is measured by a solid state detector (SSD). Electrical signals from the detector are analyzed by a spectroscopy digital signal processor (DSP), which outputs the diffraction spectrum. This method is primarily used for measuring strain in structural materials and identifying minerals within samples.

However, the conventional software used to control the spectroscopy DSP lacked network communication capabilities, which prevented synchronized measurements with other equipment such as motor-driven stages. To solve this problem, we developed new software that supports network communication. Figure 2 shows the new software's interface. This software allows the DSP to be controlled via a GUI and can also accept commands over a network at any time.

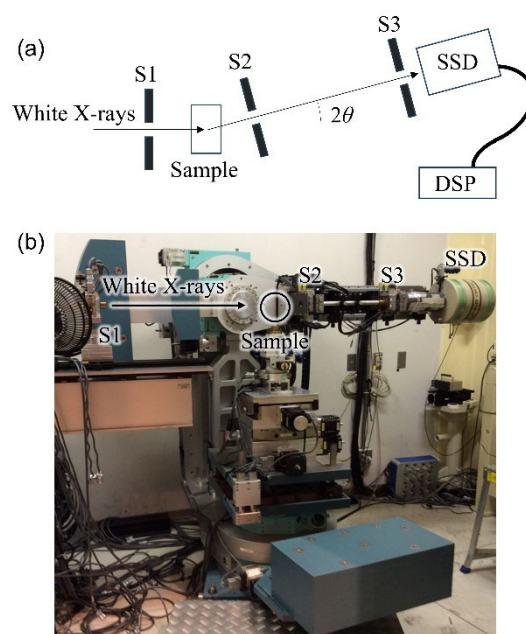


Fig. 1. Layout of energy-dispersive X-ray diffraction (a) and a photograph of the white beam diffractometer system (b).

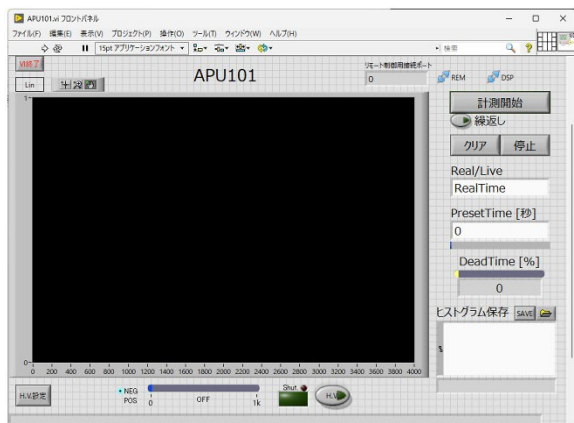


Fig. 2. User interface of the new software for controlling the spectroscopy DSP.

2-2. High-energy X-ray micro-CT

High-energy X-ray micro-CT at the 200 keV region has been applied to the nondestructive three-dimensional observation of metallic cultural heritages, large and dense fossils and so on [1, 2]. In addition to these conventional scans, it is expected to be applied to the high-resolution observation of small features or their local fine structures. Here, the measurement condition was examined by focusing on the visible-light optical system of a visible-light conversion-type X-ray imaging detector to evaluate the achievable spatial resolution in X-ray micro-CT at 200 keV.

In the visible-light conversion-type X-ray imaging detector, the incident X-ray beam onto the detector is converted into a visible-light image by a scintillator. Then, the visible-light image on the scintillator is magnified or demagnified by the lens system and ultimately detected with a CMOS camera. Therefore, the characteristics of visible-light optics including the scintillator greatly affect the spatial resolution of the X-ray image. Since the high-energy X-ray beam easily penetrates even a thick scintillator (more than 70% transmission for LuAG with a thickness of 1 mm at 200 keV), its

effective thickness that contributes to image formation is an important parameter in achieving a high-resolution observation. There are two ways to change the effective thickness: one is to alter the thickness of the scintillator itself and the other is to adjust the apparent thickness when changing the aperture size of the lens system, which is relevant to the effective depth of focus on the scintillator. Here, the spatial resolution when the thickness of the scintillator and the aperture size of the lens system were changed was evaluated from actually obtained X-ray micro-CT images [3]. In this case, the spatial resolution was estimated from the edge response of a sectional image of a molybdenum (Mo) rod with a diameter of 1.5 mm. The line spread function (LSF) obtained from differentiating the profile was fitted with a Gaussian curve. Then, the full width at half maximum (FWHM) of the Gaussian curve was defined as the spatial resolution. In the tomographic observation of the Mo rod, the effective pixel size was set to 1.69 μm , which is almost the minimum pixel size available in X-ray micro-CT at 200 keV. The propagation distance from the sample to the detector was set to 500 mm. The number of projections was 3600, and the exposure time was such that the background intensity remained almost the same under all conditions. The scintillator was LuAG ceramics, and 500- μm -thick and 200- μm -thick plates were employed. Sectional images of the Mo rod and their magnified images when the aperture size of the lens (F number) on the scintillator side of the tandem lens system was changed as F2 (maximum aperture), F2.8, F4, and F5.8 are shown in Fig. 3(a). An example of the edge profile and its Gaussian fitting when the thickness of the scintillator and the aperture size were 200 μm and F2, respectively, is shown in Fig. 3(b). The

spatial resolutions estimated under all conditions are plotted in Fig. 3(c). The error bars represent the standard deviation of values measured at four different locations. The spatial resolution could be improved by employing a thinner scintillator and also by increasing the effective depth of focus with a smaller aperture size in the current setup, whereas the theoretical resolution would generally be deteriorated by employing a smaller numerical aperture. As a result, a spatial resolution better than $6\ \mu\text{m}$ could be achieved in X-ray micro-CT at 200 keV although the measurement time became longer.

In the future, local high-resolution observation is expected to be applied to the observation of fine structures in dense samples such as fossils, batteries, and metallic devices that require measurements with high-energy X-rays. In addition, the multiscale observations combined with wide field of view observation would also be a powerful tool in understanding the detailed structures of such samples.

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References:

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- [2] Imai, T. Hattori, S. Uesugi, K. & Hoshino, M. (2023). *J. Synchrotron Rad.* **30**, 627–633.
- [3] Hoshino, M. & Uesugi, K. (2023). *AIP Conf. Proc.* **2990**, 040016.

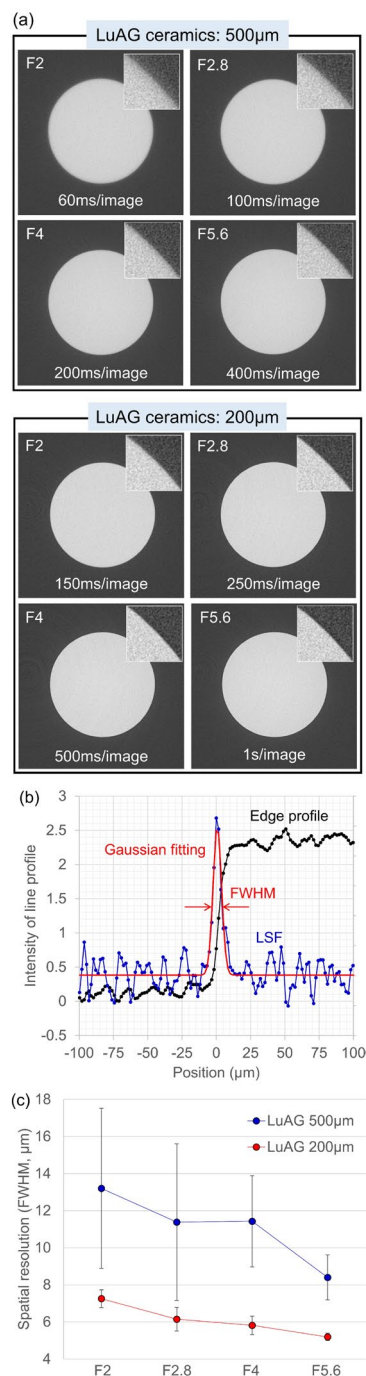


Fig. 3. (a) X-ray micro-CT images of Mo rod under respective measurement conditions. The inset in each image shows the magnified image of the upper right part. (b) Edge profile and its Gaussian fitting for the image taken with the 200 μm scintillator and F2 aperture. (c) Spatial resolution estimated from the edge profiles.