BL47XU
Micro-CT

1. Introduction

BL47XU, which is an X-ray undulator beamline, is dedicated to micro/nano-CT and high-speed X-ray imaging. Those experiments require a high-flux-density monochromatic beam. To handle the high heat load of the undulator, a liquid-nitrogen (LN_2) cooling system is used to cool the monochromator crystals. The available energy range is between 6 keV and 37.7 keV, with a Si (111) reflection of the monochromator. To eliminate higher harmonics, a set of reflection mirrors (double-bounce in the vertical direction) can be inserted.

The beamline has two experimental hutches (EH1 and EH2), which are located just after the optics hutch. EH1 contains experimental tables for X-ray micro/nano-CT, while EH2 contains some X-ray optics and X-ray image detectors for nano-CT. Half of EH2 can be used as an open hutch for users who bring their own special equipment. In FY2021, two apparatuses were installed and used for general experiments. They are a high-stability positioning system for X-ray optical devices and high-precision stages for micro/nano-CT. The details and some results are described here.

2. Introducing high-stability positioning system for Fresnel zone and Zernike phase plates

A new setup of the Fresnel zone plate (FZP) for the objective [1] and the Zernike phase plate (ZPP) to be placed at the back focal plane of the FZP is described in this section. Two sets of FZP and ZPP are used for each to accommodate a wide energy range between 7 keV and 15 keV. The diameters and outermost zone width of the FZP are 310 μm and 620 μm, and 50 nm, respectively. The zone material of FZPs and ZPPs is tantalum, which is deposited on the SiC membrane with a thickness of 2 μm. The details of the parameters are described elsewhere [2]. They are placed in a helium gas chamber to prevent damage and carbon deposition due to X-ray irradiation. There are two same-type chambers for FZPs and ZPPs. Figure 1 shows the inside view of the ZPP chamber. There are two X-ray beam paths for different ZPPs. There are some screw holes to set the ZPPs at different positions in the X-ray optical path for different focal length and X-ray energy. SiN membranes (1 μm thick, NORCADA Inc., Canada) are used for the window material. Helium gas constantly flows during the experiment. The flow rate is about 15 mL/min.

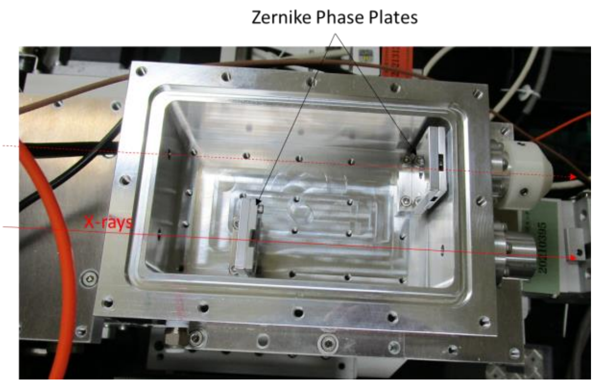

Fig. 1. Photograph of inside of phase plate chamber. Two types of ZPP can be set in its chamber. By translating the chamber, the appropriate one can be selected for the X-ray energy. The chamber is filled with helium gas.

Those chambers are placed on high-precision stages to adjust the positions. Figure 2 is a side view of the setup. The stage can move all optical elements in three axes (X, Y, and Z directions). This enables alignment to the X-ray optical path and the focus adjustment of the FZPs. The ZPPs have other three axes because they have to be aligned to the FZPs. A high-spatial-resolution image detector is placed on the large horizontal translation stage (Yellow X in Fig. 2) with some other axes; therefore, multi-scale measurement is possible without a dismount specimen.

Although many cables are connected to each stage, they are properly positioned to achieve high stability and position reproducibility.

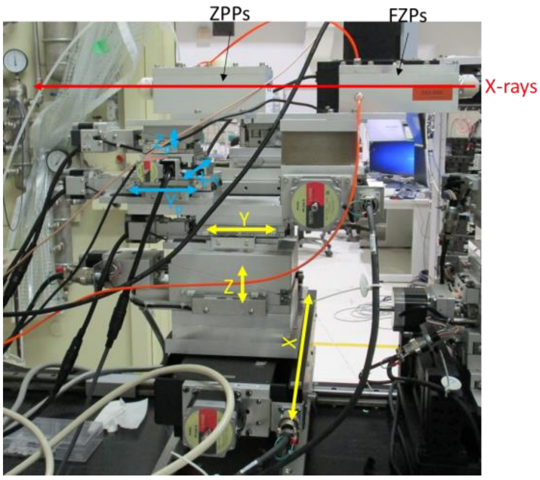

Fig. 2. Photograph of high-precision stages for X-ray optical devices. The yellow and light blue arrows show the travel directions of each stage of whole devices and phase plates, respectively.

3. Introducing high-precision stages for samples

The high-precision stages for samples were also replaced. In particular, the stage used for height adjustment (ZA16A-32F01-1Q) sometimes gave an unexpected lateral drift of several micrometers after the position change. Therefore, it was replaced with a wedge-type vertical translation stage (ZA16A-W2C01). The unexpected lateral drift was eliminated; however, the travel distance (±8 mm) was insufficient for various types of sample. A new vertical translation stage (CZA16A-W2L35-SR) has been developed and provided by Kohzu Precision. It is of the wedge type, and the travel distance is more than ±15 mm. It is highly suitable for this purpose. Tilt and horizontal translation stages are standard products with less than 1 μm repeatability. A rotation stage (SPU-1A) is attached on the top with an XY translation stage for micro/nano-CT measurement. The XY translation stage is connected through a slip ring for free rotation.

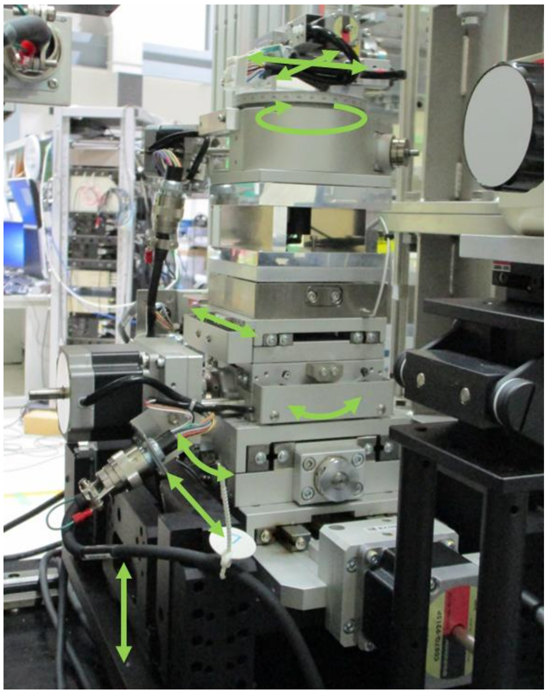

Fig. 3. Photograph of high-precision stages for samples. The arrows show the travel direction of each stage.

4. Evaluation about stability and sample rotation

The X-ray microscope optics (nano-imaging system) was evaluated using the above system. The stability and rotational accuracy of the rotation stage are described in this section. The stability of the measurement system was evaluated using a test chart for X-rays (XRESO-50HC, NTT-AT). X-ray images of the chart were taken every 10 min for 10.3 h. The exposure time of each image was 500 ms. The effective pixel size was 48 nm/pixel. The X-ray image detector consists of a scintillator (single-crystal GAGG, 200 μm thick), tandem lens optics (f = 20 mm, f = 85 mm), and an sCMOS camera (ORCA Flash 4.0 v3, Hamamatsu Photonics K. K.).

Two images are shown in Fig. 4 (top). They were taken at the beginning and end of the measurement. The averaged line profiles are shown at the bottom. The difference in the position of the test chart is 72 nm in the horizontal direction. There is almost no difference in the vertical direction. The typical measurement time of nano-CT is from a few minutes to one hour. Therefore, the stability is sufficient for nano-CT because the average amount of drift is about 7 nm/h.

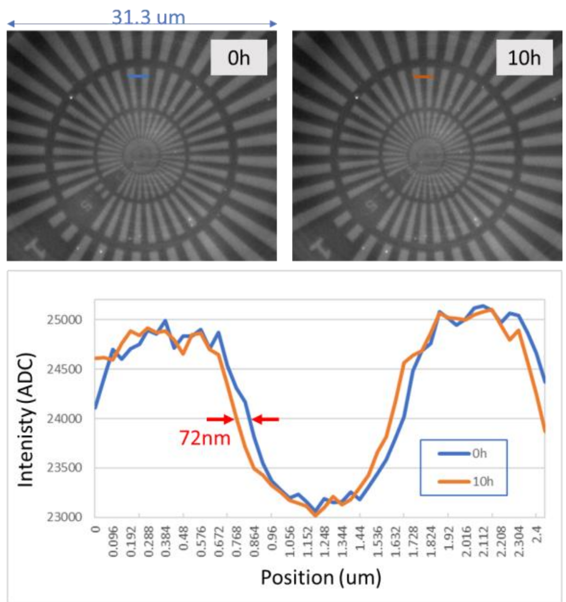

Fig. 4. (Top) Transmission images of test chart between the images taken 10 h apart. (Bottom) Averaged line profiles (10 lines) in those images. The red arrows show the distance of the pattern edge.

The wobble of the rotation stage was also measured. The specimen was a tungsten needle. It was put on the rotation stage using a sample holder, then a two-rotation sinogram was taken to check whether there was an irregular movement. The images were taken every 0.1 degree with the exposure time of 250 ms. The total measurement time was about 40 min. The repeatability of the position according to the equivalent rotation angle is sufficient. Furthermore, no irregular fluctuations are seen in the magnified view on the right side, which indicates that the wobble is less than 100 nm.

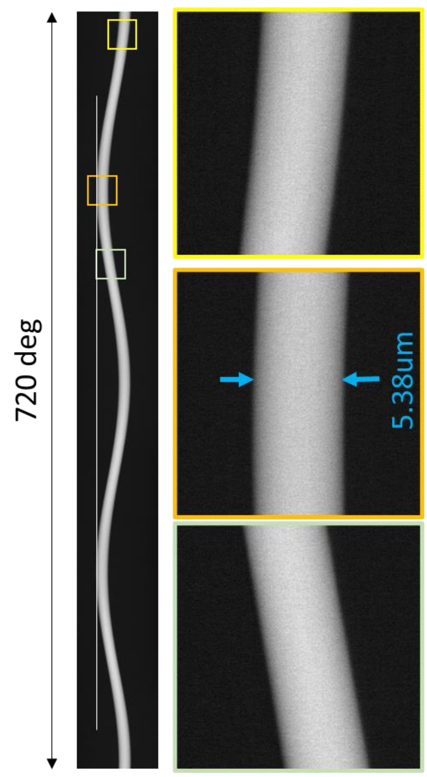

Fig. 5. (Left) 720 degree (two rotations) sinogram of tungsten needle. The additional line shows the left edge of the needle. (Right) Enlarged views of the figure on the left. The colors of the frames correspond to each other.

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References:

[1] A. Takeuchi et al. (2017). *J. Synchrotron Rad*. **24**, 586.
[2] K. Uesugi et al. (2022). *AIP Conf. Proc.* Accepted.