BL29XU
RIKEN Coherent X-ray Optics

1. Introduction

BL29XU is a 1-km-long beamline for which the light source is a standard undulator with a length of 4.5 m. This beamline consists of an optics hutch and four experimental hutches. Various R&D projects are performed on instruments in the front-end and transport channel sections, such as the double-crystal monochromator, higher-harmonic-rejecting double mirrors, transport channel slits, and beryllium windows. Infrastructure development for advanced scientific studies is intensively carried out at BL29XU, especially for making full use of the spatial coherence of X-rays. The efforts include the reduction in the number of beryllium windows placed along the optical axis and the suppression of vibrations of the monochromator in the transport channel. These developments directly impact the quality of experiments, such as coherent X-ray diffractive imaging (lensless X-ray microscopy) and total-reflection mirror optics experiments, with ultimate precision.

The downstream mirror, which rejects higher harmonics, contains two strips of parabolic mirrors with a focal length of approximately 48 m. This is equal to the distance between the mirror and the light source. The glancing incidence angle can be set to 5 or 3 mrad. The downstream mirror also contains a strip of a flat mirror. Parabolic mirrors can provide a parallel X-ray beam by reflecting X-rays emitted from the source approximately 48 m upstream. By reflecting 8 keV X-rays on a parabolic mirror with an incidence angle of 5 mrad, the measured vertical angular divergence is reduced from 9 μrad without mirrors to 0.4 μrad.

2. Recent activities

We are working intensively to fulfill another critical task of BL29XU: the calibration of various state-of-the-art X-ray detectors and X-ray optical components developed by SPring-8 users and outside users.

The X-ray diffused light was formed for the calibration of the X-ray telescope mirror having a large focal length of around 2 m, which was actually launched on a NASA sounding rocket experiment in early FY2024. The X-ray diffused light was formed as the -1st-order light from a Fresnel zone plate (FZP) and was expected to be an approximately 90 mm beam at EH4 inside the 1 km beamline building, large enough for taking a snapshot of a focused image by the X-ray telescope mirror with a diameter of 60 mm. The realized beam, however, manifested shadows on the 90 mm beam, resulting from the vacuum pipes whose positions shifted gradually over >10 years, which resulted in blocking the X-rays (Fig. 1, left). We analyzed the geometry and made a guess of the major locations of the shifted vacuum pipes and the shifted amounts at these locations. Using this result, the vacuum pipes have been relocated 40 mm upwards and 20 mm towards the SACLA building side (north), respectively, near pump housings #49 and #50 (among 64 housings). With this relocation during the summer shutdown of FY 2024, the blockage of the X-ray beam by the vacuum pipes has been significantly reduced (Fig. 1, right).

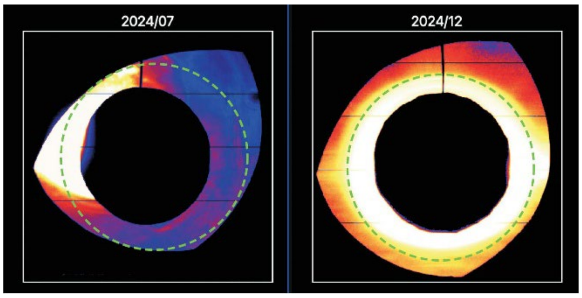

Fig. 1. Blockage of X-ray beam by multiple vacuum pipes located between EH3 and EH4 of BL29XU. This was markedly improved from (left) Jul. 2024 to (right) Dec. 2024, corresponding to before and after the relocation of the vacuum pipes. The diffused light is formed by the −1st-order light of FZP, while the 0th-order light is blocked by a direct beamstop at the center. The green dotted circle shows the outer diameter of the X-ray telescope mirror.

Hereafter, we present the research highlights achieved at BL29XU during fiscal year 2024.

A research team headed by Prof. Matsuyama and Dr. Inoue at Nagoya University has succeeded in fabricating a deformable X-ray mirror consisting of a single thin piezoelectric single crystal wafer, composed of lithium niobate (LN) with a thickness of 0.5 mm, which enabled the change in X-ray beam size by 3400 times by varying the focal length. When LN is heated to a high temperature of approximately 1000 °C, the polarization structure partially changes, forming a bimorph structure without bonding, which enables them to fabricate an extremely thin mirror and create surfaces with a variety of curvatures. By further thinning, this type of novel mirror is expected to be used in a wide range of wavelengths, including visible light, in addition to the X-ray range [1].

A research team headed by Prof. Matsuyama and Dr. Inoue at Nagoya University has developed a method of determining the X-ray transmissivity and phase shift through the sample by analyzing multiple blurred X-ray microscopy images acquired by rotating the sample in-plane. These multiple images are affected by common blurring due to lens manufacturing errors, alignment errors of microscopy images, and wavefront aberrations. Their analysis enabled them to separate the blurring by making full use of AI technology (neural networks with physical constraints). Since manufacturing lenses is difficult and blurring is unavoidable in the X-ray regime, this method is proven to be extremely powerful. It will be helpful for achieving high-resolution X-ray microscopy with a minimal effect of this blurring [2].

A research team headed by Prof. Takahashi and Dr. Abe at Tohoku University proposed a phase retrieval method that enhanced amplitude image reconstruction by exploiting the structural similarity between phase and amplitude images through guided image filtering. The results of numerical simulations and synchrotron radiation experiments demonstrated that it could reconstruct amplitude images with quantitative accuracy comparable to that of ptychography and attained a spatial resolution equivalent to that of phase images. This technique could potentially revolutionize material characterization by improving the temporal resolution of nanoscale chemical-state imaging [3].

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References:

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[2] Kurimoto, S. et al. (2024). *Sci. Rep.* **14**, 29726.

[3] Abe, M. et al. (2024). *Optica* **11**, 12