BL29XU
(RIKEN Coherent X-ray Optics)

BL29XU is a unique 1-km length beamline. The light source is a standard undulator with a length of 4.5 m. This beamline
e consists of an optics hutch and four experimental hutches. Various R&D projects are performed on the instruments in the front-end section as well as the transport channel section such as the double crystal monochromator, higher-harmonics rejecting double mirrors, TC slits, and beryllium windows. The vibration of the double crystal monochromator was intensively studied and was significantly reduced. Among the double mirrors to reject higher harmonics of light, the downstream mirror contains two strips of parabolic mirrors. The mirrors have a focal length of approximately 48 m, which equals the distance between the mirror and light source, realizing two settings of the glancing incidence angles of 5 mrad and 3 mrad. This mirror also contains a strip of a flat mirror. The parabolic mirrors allow a parallel X-ray beam to be obtained by reflecting X-rays. Reflecting 8-keV X-rays on a parabolic mirror with a 5-mrad incidence angle reduces the vertical angular divergence from 9 μrad without mirrors to 0.4 μrad.

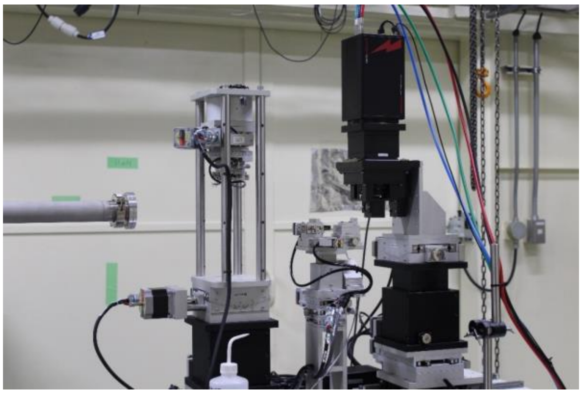

Fig. 1. Photograph of phase CT equipment designed and manufactured in FY2018. X-rays are incident from the left side and illuminate the sample, which is a phase object set on a rotation stage. Modulated phase due to the sample is measured by analyzing the interferogram obtained by a Talbot interferometer using a phase grating and an amplitude grating. Detector is set on the *xz*-translation stage and a tilt stage.

The most advanced uses of coherent X-rays are intensively pursued at BL29XU. These include coherent X-ray diffraction imaging (lensless X-ray microscopy) and total-reflection mirror optics development with ultimate precision. An instrument for high spatial resolution computed tomography (CT) has also been extensively developed. High-speed CT equipment for on-the-fly measurements was constructed in FY2017. In FY2018, highly mobile phase CT equipment based on Talbot interferometry was designed and manufactured (Fig. 1). It consists of stages for sample alignment, double gratings (a phase-type and an amplitude-type), and an imaging detector.

The most advanced scientific results achieved in the fields of X-ray coherent imaging are briefly described as follows. Until FY2017, the collaboration team of Y. Takahashi and M. Tada, which belong to the Structure Visualization Team of RIKEN SPring-8 Center, combined hard X-ray ptychography and CT techniques to acquire EXAFS properties of three-dimensional samples with a 50-nm spatial resolution. The method is named 3D-HXSP (Hard X-ray Spectro-Ptychography) method. Using data science, they visualized and traced the oxidization process inside a material. Their result will be applicable to the analysis of chemical states of nanostructures in various advanced functional materials [1].

The static structure and dynamics of aqueous hydroxyapatite colloids were investigated by SAXS and XPCS. Above a certain concentration, a phase transition occurs between the isotropic and liquid crystal phases, and the scattered image changes from axisymmetric (circular) to an anisotropic [2].

The X-ray vortex has an orbital angular momentum (OAM), and can be used as a probe for novel spectroscopy via the interaction, which depends sensitively on the X-ray OAM and the spin angular momentum in the material. A clockwise or an anti-clockwise spiral phase distribution with integer multiples of 2π around the center is indistinguishable from the identical image of an X-ray vortex beam with a donut ring and a zero intensity at the center.

Y. Taira, who belongs to the SR Imaging Instrumentation Team of RIKEN SPring-8 Center, developed a method to discriminate the OAM of the focused X-ray vortex beam using a diffracted image through a triangular aperture set at the focal plane. The simple method meets the requirement for the novel spectroscopy [3].

T. Kameshima, who belongs to the JASRI XFEL Utilization Division, developed an X-ray indirect imaging detector. This detector converts the X-ray to visible light using a cerium-doped ceramic LuAG ($Lu_3Al_5O_{12}$) scintillator on a transparent ceramic layer of a non-doped LuAG substrate. He showed that this detector can resolve a Line and Space (L&S) pattern with a pitch of 200 nm and a relatively high contrast [4]. This detector is best suited for three-dimensional imaging of buried wirings in semiconductors or resolving various organs or neurons in biological specimens. Finally, experiments to evaluate various optical elements (*e.g.*, self-seeding crystal optics) and detectors (*e.g.*, SOPHIAS and CITIUS detectors) for SACLA and SPring-8 II facilities were intensively performed at BL29XU.

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References:

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[2] T. Hoshino et al., *Soft Matter* **15**(16), 3315 (2019).

[3] Y. Taira and Y. Kohmura, *J. of Optics* **21**, 045604-1-5 (2019).

[4] T. Kameshima et al., *Optics Letters* **44**(6), 1403-1406 (2019).