1 Newly Developed Experimental Facilities

1-1 Overview

Since 2005, we have carried out the beamline refurbishment program based on a well-defined beamline strategy and the areas of excellence that had been discussed with the PF users' community. The mainstay of the beamline strategy is to concentrate investment on the competent beamlines with insertion devices as light sources.

With the reinforcement of the straight sections of the 2.5-GeV PF ring, which was completed in 2005, the long and medium straight sections have been made longer so that more powerful insertion devices can be installed to cover the vacuum ultraviolet and soft X-ray region, and four new short straight sections have been produced for the installation of short period and small gap undulators (SPSGU) to supply well focused hard X-rays.

Beamlines BL-13, BL-16 and BL-28 were constructed originally for sharing the photon beam between VSX and HX users by operating the insertion device in the undulator and multipole wiggler mode. Among the three beamlines, BL-28 was renewed first as a high-performance spectroscopic beamline dedicated to photoelectron spectroscopy in the VSX region, and the second branch has been open for users' experiments since 2006. BL-16 has been completely upgraded as a fast polarization switching soft X-ray spectroscopic beamline including the beamline and the insertion device. Two tandem APPLE-II type undulators are set to different polarizations such as right- and left-hand circular polarizations, and the polarization is switched by modulating the electron orbit through the undulators, as reported in the previous activity report [1]. BL-13 was recently reconstructed as a VSX spectroscopic beamline for studying organic thin films adsorbed on well-defined surfaces using angle-resolved photoelectron spectroscopy, high-resolution X-ray photoelectron spectroscopy and X-ray absorption spectroscopy. The detailed performance was described in the last PF activity report [2].

The VSX beamline refurbishment program has required replacement of the insertion devices at BL-13 and BL-28, which were constructed in the 1980s for supplying photon beams in the VSX and HX regions. These old insertion devices do not always meet the needs of VSX users and are not adequate for utilizing the full performance of the newly constructed beamlines. Furthermore, during the test operation of the PF ring and the beamlines in June 2011, after the Great East Japan Earthquake on March 11, 2011, we found some troubles caused by earthquake damage to these old insertion devices. Therefore, these two old undulators should be replaced by new ones appropriate for the renewed beamlines.

BL-2 was the first undulator based VSX beamline constructed in the early 1980s, and has been operated for over 25 years. The BL-2 undulator is 3.6-m long, while the length of the straight section is 9 m following the reinforcement in 2005. There are several options for making the best use of this long straight section, such as installing a long undulator or adding a long-period undulator. The beamline optics of the present BL-2 need to be renewed or improved in choosing one of these two options.

The short straight sections have been used for installing an SPSGU to supply hard X-rays. We have already constructed three HX beamlines at the short straight sections: BL-3 for materials science, and BL-1 and 17 for macromolecular crystallography. In the last straight section, we are planning to construct a complex analysis beamline using small X-ray scattering and X-ray absorption spectroscopy at BL-15.

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[1] *Photon Factory Activity Report 2010,* **#28** (2012) A 83.
[2] *Photon Factory Activity Report 2010,* **#28** (2012) A 82.

1-2 BL-6A: Small Angle X-ray Scattering Beamline

As reported previously, BL-6A was reconstructed for small-angle X-ray scattering (SAXS) experiments [3]. The activities that have been carried out at BL-15A were moved to the new BL-6A. The BL-15A site will be scrapped and instead a new undulator beamline for SAXS and X-ray absorption spectroscopy will be built in 2013.

The reconstruction of BL-6A began in FY2009. The old hutch and beamline components were scrapped immediately after the ring operation in March 2010. The new experimental hutch and deck with facility work were completed in FY2010 [3]. The beamline optics and diffractometer were installed in 2011. All the reconstruction work was completed during the summer shutdown of 2011. After a short commissioning and 2-day user training upon starting operation in autumn 2011, we started user operation on October 18, 2011.

The beamline layout of BL-6A is almost the same as that of BL-15A [3]. The main optics are a vertically focusing bent flat mirror and an asymmetrically cut monochromator crystal optimum for 8-keV X-rays. The surface of the mirror that had been used for a long time at the old BL-6A was cleaned by UV/ozone ashing [4], courtesy of the Light Source and Optics Division of JASRI/SPring-8. The SAXS/WAXS diffractometer used at

BL-15A [5] was installed in the experimental hutch. Two slits just after the monochromator and on the diffractometer are used for defining the beam size and preventing scattering to eliminate parasitic scattering, respectively. Two types of CCD detectors, C4880-10 and C7300 (Hamamatsu Photonics), equipped with two different sizes (6 and 9 inches) of X-ray image intensifiers (Hamamatsu Photonics) are available for SAXS experiments. A newly developed detector stage was installed to control the positions of these SAXS detectors (Fig. 1). A flat-panel sensor, C9728DK-10 (Hamamatsu Photonics), for WAXS experiments can be set on motorized stages for such experiments [5]. For the SAXS/WAXS simultaneous experiments, a digital delay pulse generator, Model 500D (Berkeley Nucleonics Corporation), is used for timing control among the detectors and apparatuses in msec order. A new BL-6A control system has been developed based on STARS, which is universally used at the Photon Factory [6]. This system can control all the motorized stages and measurement apparatuses via the network and several user-friendly GUI programs are provided.

Preliminary characterizations of the beam were carried out after tuning the optics. The FWHM beam size at the focal point was 0.498 mm (H) × 0.245 mm (V), measured with a flat-panel sensor (C10013SK, Hamamatsu Photonics). This result is comparable to 0.443 mm (H) × 0.188 mm (V) which is calculated by the raytracing program, SHADOW [5]. The photon flux at the sample position measured with an ionization chamber (S-1329A, Oken) was estimated to be 1.0×10^{12} phs/s and 3.6×10^{10} phs/s for the full-open and 0.6×0.6 mm^2 of the size-defining slit, respectively. These beam performances are promising for various SAXS activities.

Figure 1
SAXS/WAXS diffractometer in the experimental hutch of BL-6A. The new detector stage is placed at the end of the diffractometer.

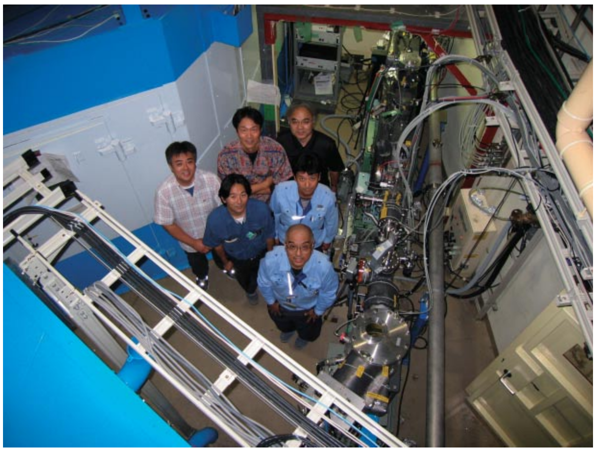

Figure 2
BL-6A construction team.

REFERENCES

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1-3 New Diffractometers Developed for Resonant Soft X-Ray Scattering Experiments at BL-16A and 11B

Various intriguing physical properties have been discovered in strongly correlated electron systems (SCES). In such systems, the strong correlation among charge, spin, and orbital of the *3d* electrons and lattice degrees of freedom play important roles, so it is important to study these electronic states to understand the phenomena microscopically. Moreover, specific properties such as high *Tc* superconductivity and colossal magnetoresistance effects have often been reported near the metal-insulator (MI) transition, where the localized electrons, *d*-electrons in transition metals and *f*-electrons in rare earth metals, and the itinerant electrons, O*2p*, P*3p*, and so on, compete with each other. For example, superconductors generally exist in the vicinity of a quantum critical point. Hence, to elucidate the origin of these physical properties it is important to study the orbital hybridized states where itinerancy and localization of electrons compete. Recently, new types of ferroelectric (FE) compound such as multiferroics have attracted much attention. In these compounds, the hybridized orbital is also a key parameter of the polarization, so it is necessary to study the hybridized orbital state. In order to clarify these electronic states and orbital hybridized states, resonant soft X-ray scattering is an important technique, because we can utilize the 3d transition metal *L*-edge, *4f* rare earth metal *M*-edge, O *K*-edge, and so on in the soft X-ray region, and thus can directly measure the electronic states dominating the physical properties. Moreover, the X-ray intensity of the soft X-ray region in the Photon Factory is much stronger than that in SPring-8. Although resonant soft X-ray scattering (RSXS) is a research subject that should be promoted in the Photon Factory, such a diffractometer has not been available so far.

Figure 3
Construction members photographed near the new diffractometer to perform RSXS measurements under magnetic field at BL-16A.

In order to elucidate the origins of physical properties in SCES, we have developed new diffractometers depending on the experimental conditions.

Figure 4(a) shows a conventional 2-circle diffractometer. To detect weak resonant signals which reflect the change of physical properties in SCES, the slits and detector must be placed in a vacuum chamber to reduce the background. Hence, the diffractometer with a large vacuum chamber was built as shown in Fig. 4(b), which can also accommodate a two-dimensional X-ray detector, a CCD camera for soft X-rays. The second diffractometer is specially designed for small angle diffraction to detect magnetic textures (skyrmions, etc.) and domain structures as shown in Fig. 4(c). We have also developed a diffractometer with a superconducting magnet (< 7.5 T) to investigate the magnetic field effect for SCES. This diffractometer has the same geometrical configuration as that at BL-3A, and we can perform studies by complementary use of hard and soft X-rays. These diffractometers are expected to lead to new discoveries in SCES.

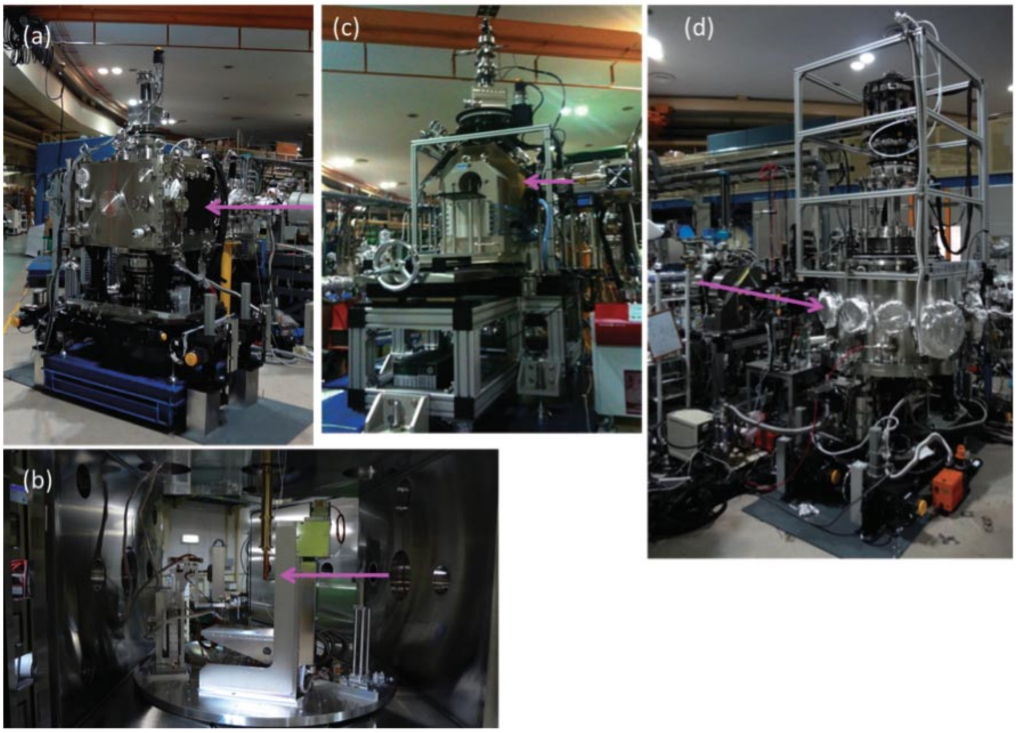

Figure 4
Conventional two-circle diffractometer: (a) outer and (b) inner side views. (c) Diffractometer for small angle resonant soft X-ray diffraction. (d) Two-circle diffractometer, which can be equipped with a superconducting magnet. Arrows indicate the direction of the incident X-ray.