Construction of New Soft X-Ray Spectroscopy Beamline BL6U

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Various types of monochromators for synchrotron radiation have been proposed and constructed to realize vibrational spectroscopy in the soft x-ray range, which contains the *K*-shell thresholds of chemically important elements like C, N, and O, since the first successful observation for the vibrational structures of the π^* resonance in the *K*-shell photoabsorption spectrum of nitrogen molecules [1]. Thanks to the high brilliance offered by undulator radiation, both high-resolution and high-flux are achievable simultaneously at a considerable high level. At the UVSOR, there is only one soft X-ray undulator beamline for high resolution spectroscopy, BL3U, in the photon energy region of interest.

A new project for constructing the undulator beamline BL6U has been recently initiated. The entrance slit-less configuration for the monochromator has been chosen. In order to cover a wide photon energy region (30-500 eV) with one single grating, a variable-included-angle Monk-Gillieson mounting monochromator with a varied-line-spacing (VLS) plane grating [2] has been selected. Design study for the monochromator at BL6U has been completed, with the collaboration of KEK-PF. The monochromator designed will cover the photon energy ranging from 30 to 500 eV, with the resolving power higher than 10000 and the photon flux more than 10^{10} photons/sec.

The resolution of the present monochromator was studied by ray-tracing simulation as well as analytical estimation. It is found that a resolving power E/ΔE of more than 10000 is achievable over the energy range from 30 to 500 eV with one single grating. The throughput photon flux estimated ranges from 10^{10} to 10^{12} photons/sec for the ring current of 350 mA, with a resolving power of 10000.

Figure 1 shows the overall picture of the beamline constructed, with pictorial indications for the incoming undulator radiation and important beamline components. In front of all optical elements, there is an aperture S_0, located 5.0 m from the source position. The radiation is deflected horizontally by a toroidal mirror M_0 located 1.5 m downstream of the aperture. M_0 converges the radiation vertically onto a virtual focal point behind the VLS grating G, and thus converging soft X-rays illuminate G. A plane mirror M_1 is located 1.5 m behind M_0. One laminar profile plane grating, which is ruled holographically, with the varied-line-spacing (500 l/mm at its center position), is designed to cover the energy range from 30 to 700 eV. The included angle of the grating should be changed from 167˚ to 176˚ in order to minimize the aberrations. A refocusing mirror M_2 has a toroidal shape, which focuses the monochromatized radiation at the sample position.

The practical construction of BL6U has started from the summer of 2008. After careful tuning of the whole system at BL6U, the first light was observed in December 2008. The performance tests of the monochromator have been performed, whose results are given in a separate page in this report. High resolution spectroscopic studies, not only in gas phase, but in solids or surfaces, are planned to be conducted there. The constructions of the apparatuses for high-resolution electron spectroscopy have also begun.

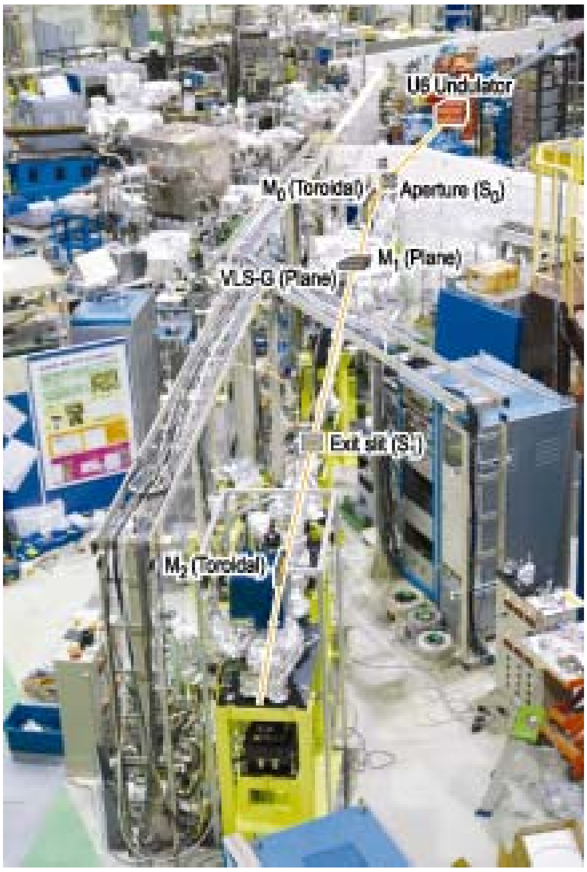

Fig. 1. Top view of the newly constructed soft X-ray spectroscopy beamline BL6U.

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Performance of New Soft X-Ray Spectroscopy Beamline BL6U

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The in-vacuum type undulator U6, which has been relocated from the long straight section U7 to the short one U6, has 26 magnetic periods and the period length is 36 mm [1]. The spectral region from 50 eV to 140 eV, which is realized by changing the gap height from 15 mm to 40 mm, was covered with the first harmonic radiation [1]. There was an inherent energy gap between the highest and lowest photon energies, covered by the first and third harmonics, respectively. Due to the relocation of the undulator, this gap has been bridged. This is because the vertical betatron function at U6 is smaller than that at U7 and the minimum gap available becomes accordingly smaller down to 10 mm. Correspondingly the tunability covered by the undulator radiation is widened: the photon energy range from 30 to 500 eV can be covered by odd harmonics up to seventh without any energy gap. Then a new project for constructing the undulator beamline BL6U has recently been initiated.

According to the theoretical estimations by using the ray-tracing program XRAY-T [2] in combination with the synchrotron radiation calculation code named SPECTRA [3], the monochromator designed for BL6U, which possesses a variable-included angle mechanism, can cover the photon energy ranging from 30 to 500 eV by one single grating, with the resolving power higher than 10000 and the photon flux more than 10^{10} photons/sec. We have carried out short performance tests of the monochromator installed.

Figure 1 shows an example of the throughput spectra measured by a gold plate located just after the exit slit. Here the exit slit opening and the undulator gap were set at 30 µm and 22.5 mm, respectively. The included angle was fixed at 171°, which corresponds to the optimum condition for 80 eV. The measured photocurrent has been converted to the photon flux, by assuming that the quantum yield of Au is equal to 3% in the entire photon energy range of interest. The slit opening of 30 µm corresponds to E/ΔE ~ 10000 at 80 eV. It is found that the photon flux of the fundamental peak around 100 eV goes over 1×10^{12} photons/sec. The photon flux in the high energy region may be improved, by changing the included angles as satisfying their optimums during the photon energy scanning.

Figure 2 displays a total-ion yield spectrum in the vicinity of the 3d ionization thresholds of Kr, measured by an imaging spectrometer. The slit opening and undulator gap were the same as the above measurement. Two Rydberg series converging to the 3d ionization thresholds are identified as indicated here. Assuming that the natural width of the Kr $3d^{-1}$ 5p Rydberg states is 83 meV [4] and the spectral profile observed is expressed by a Voigt function, the monochromator band-pass is estimated to be ~25 meV. Since the theoretical value is about 10 meV around 90 eV, there is room for improvement on the resolving power.

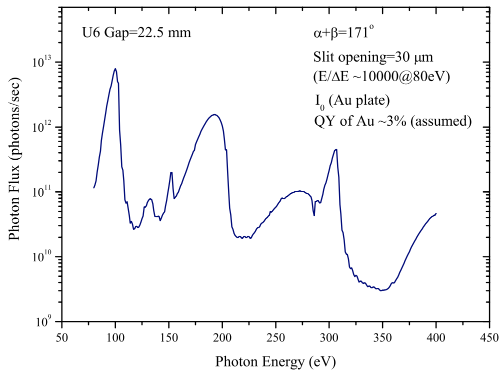

Fig. 1. Estimated throughput spectrum from the VLS-PGM at BL6U.

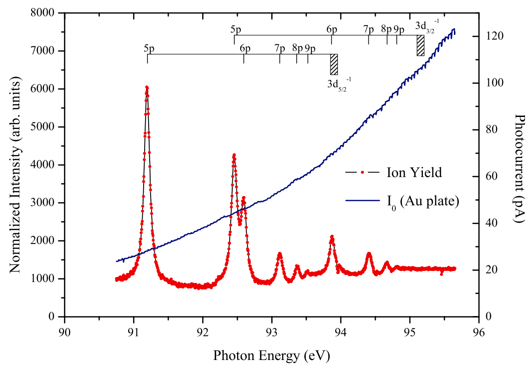

Fig. 2. Total-ion yield curve measured in the region of the 3d subshell of Kr.

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BL7U

Present Status of UVSOR-II BL7U for VUV Angle-Resolved Photoemission Spectroscopy of Strongly Correlated Electron Systems

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BL7U, the VUV angle-resolved photoemission (ARPES) beamline for advanced studies of strongly correlated electron systems, has been constructed in FY2006 and opened for users in FY2007 [1]. To satisfy the needs from users, especially (1) higher photon-flux, (2) reduction of higher-order light and (3) better base pressure of the photoemission chamber, we have improved the beamline in FY2008. As a result, we successfully achieved the sufficient throughput for ARPES experiments.

To improve the photon-flux especially at the bulk-sensitive low photon-energy ($h\nu < 15$ eV), we updated the lowest photon-energy grating G3 from Au-coating to SiC-coating one. After the update of G3, we realign the beamline to be optimized with the center of the undulator light. As a result, the photon flux as well as the focusing at the sample position has intensively been improved than that in FY2007. Figures 1(a), (b) and (c) show the improved throughput spectra obtained at low (red line)-, medium (red line)-, and high (red, yellow, green, blue lines)-photon energy regions compared with the previous one (black lines), respectively. At each energy region, the spectrum becomes sharper and shifts to the higher energy side in the same condition, indicating successful alignment with the optimum parameter of the undulator light. Clear vibration sub-bands observed higher and lower energy side of the main peak of the throughput spectrum (Fig. 2), which is consistent with a calculation, ensures the correct alignment getting the center of the undulator light.

To reduce the intensity of higher order light at the low photon-energy region, we equipped a VUV filter of MgF_2 just after the exit slit. As a result, we successfully reduced the higher-order light above $h\nu = 11$ eV (see Fig. 3). Typical loss of efficiency by the filter is less than 10%, which ensures sufficient throughput for VUV ARPES experiments with bulk-sensitive low-photon energies.

Finally, to improve the base pressure at the sample, we added a cryopump (ULVAC Cryogenic Inc., U8H) and an ion pump (ULVAC, PST-200CX2) to the photoemission chamber. As a result, we achieved the base pressure of 5×10^{-9} Pa better than before (2×10^{-8} Pa). For further improvement of base pressure, we plan to equip a thermal radiation shield around the sample in FY2009.

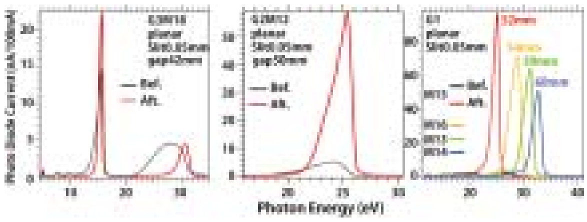

Fig. 1. Improvements of throughput spectra before and after the realignment of optics at BL7U.

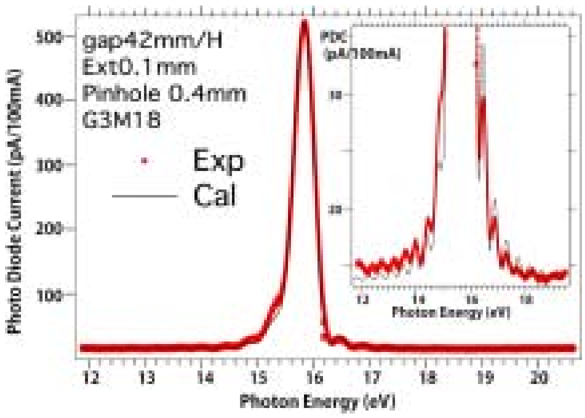

Fig. 2. Throughput spectrum at low photon-energy region in comparison with the calculation.

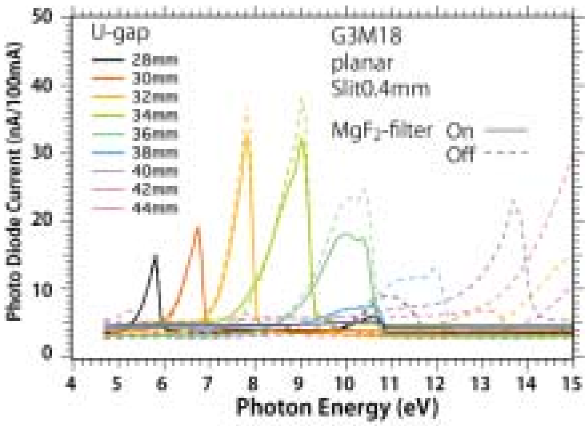

Fig. 3. Throughout spectra with some undulator gap size with and without a VUV filter, MgF_2, in the low photon-energy region.

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