BL5U at UVSOR-II for Three-dimensional Angle-resolved Photoemission Spectroscopy

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Abstract. BL5U at UVSOR-II has been reconstructed in 2004's for three-dimensional angle-resolved photoemission (3D-ARPES) study on solids and surfaces. The beamline is equipped with a helically/linearly polarized undulator, an old-type monochromator named as SGM-TRAIN designed in 1995's, and a new photoemission end-station. Since their performances are insufficient to study anomalous electronic/magnetic properties on materials in recent years, we reconstructed the beamline for a high-resolution study as follows; (1) The manipulation of the pre-focusing mirror was updated to a high-precision system controlled by pulse-motors. (2) The entrance slit with water cooling system was adopted for avoiding the heat load from undulator radiation. (3) The SGM-TRAIN was re-arranged to the optimum condition to the undulator light. (4) The free tuning program of the undulator gap and monochromator-control systems was introduced. Due to the reconstructions, we successfully improved the throughput intensity and energy resolution of the beamline to be able to investigate three-dimensional electronic-structures using 3D-ARPES.

Keywords: angle-resolved photoemission, beamline reconstruction, UVSOR-II, strongly correlated electron systems
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INTRODUCTION

Functionalities (superconductivity, magnetism, etc.) of materials originate from the electronic structure near the Fermi level (E_F), especially the Fermi surface. To pursue the origin of the functionalities on materials, we have constructed a new high-energy-resolution photoemission apparatus at the beamline BL5U of UVSOR-II, Institute for Molecular Science, Okazaki, Japan. The beamline is designed for high-energy-resolution three-dimensional angle-resolved photoemission (3D-ARPES) study on solids and surfaces with the horizontally and circularly polarized synchrotron radiation from the variably polarized undulator. The beamline consists of a variable polarized undulator (circular, planar polarization), a Spherical Grating Monochromator with Translational and Rotational Assembly Including a Normal incidence mount (SGM-TRAIN), and a high-resolution angle-resolved photoemission spectrometer.

After the upgrading of UVSOR, in which the electron-beam emittance was reduced from 190 to 27 nm·rad and the name was changed to UVSOR-II, BL5U has been reconstructed in FY2004 for a high-resolution photoemission (HRPES) study on solids and surfaces. The energy and angular resolutions of the photoemission apparatus of the BL5U end-station have been improved to $\Delta E \sim 1.2$ meV and $\Delta\theta \sim \pm 0.1$ degree, respectively, estimated by utilizing a He-Iα ($h\nu$=21.216 eV) discharge lamp. Thus, at least for the endstation, the performance is available for studying the anomalous physical properties such as metal-insulator transition, superconductivity, magnetic phase transition, etc. On the other hand, there is a problem with the beamline. For example, the SGM-TRAIN has been aligned to the bending magnet radiation (B5) because the bending magnet radiation was mainly used as the light source of the beamline before the upgrading of UVSOR. So, it was necessary on the SGM-TRAIN to be set on the line of the undulator (U5), and on some parts of beamline to be upgraded. In this paper, the present performance of the SGM-TRAIN and the end-station after the improvements are reported.

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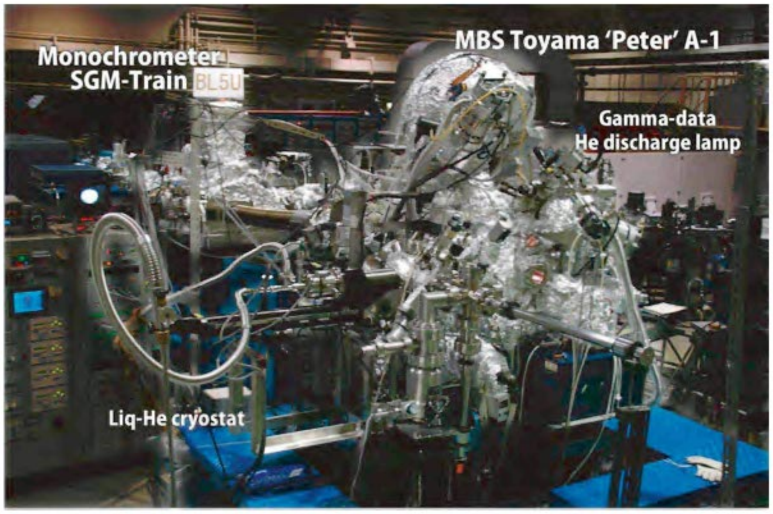

FIGURE 1. High-energy-resolution angle-resolved photoemission apparatus at UVSOR-II BL5U.

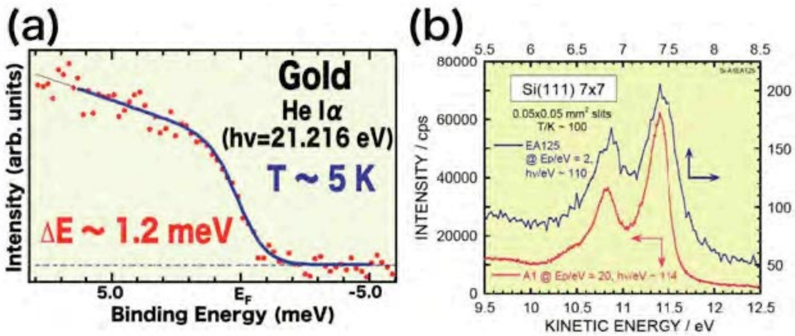

FIGURE 2. Energy-resolution test of the photoelectron analyzer (MBS-TOYAMA 'Peter' A-1) at UVSOR-II BL5U. (a) PES spectrum at around E_F of gold film obtained by using He Iα photons at 5 K (circles). The results of the fitting using the Fermi-distribution-function is superimposed (line). (b) Si $2p$ photoemission peaks obtained with the previous (gray) and present (black) apparatus installed at UVSOR-II BL5U.

STATUS OF THE END STATION AT UVSOR-II BL5U

Figure 1 shows a present status of the apparatus installed at BL5U. The most striking point is a new type hemispherical photoelectron analyzer, MBS-TOYAMA 'Peter' A-1. The photoelectron analyzer achieved the experimental energy-resolution of $\Delta E \sim 1.2$ meV, which has been evaluated from the fitting of the PES spectrum near E_F of gold by temperature-dependent Fermi-distribution-function broadened by a Gaussian meaning the energy resolution (Fig. 2(a)) [1]. The achieved energy-resolution is almost comparable to the world best (sub-meV) one [2, 3].

To evaluate the improvement of the photoemission spectrometer for BL5U, the PES spectrum of Si(111) 7×7 surface obtained by the present apparatus is compared with previous one (Fig. 2(b)). In Figure 2(b), the present spectrum seems to have some advantages to the previous one, *i.e.*, the better S/N ratio, the sharper double peak structure originating from Si $2p$ spin orbit splitting, in spite of the compatible experimental conditions (photon energy, temperature, slit size, surface preparation). The observed differences indicate the improved efficiency as well as the energy resolution of the present spectrometer.

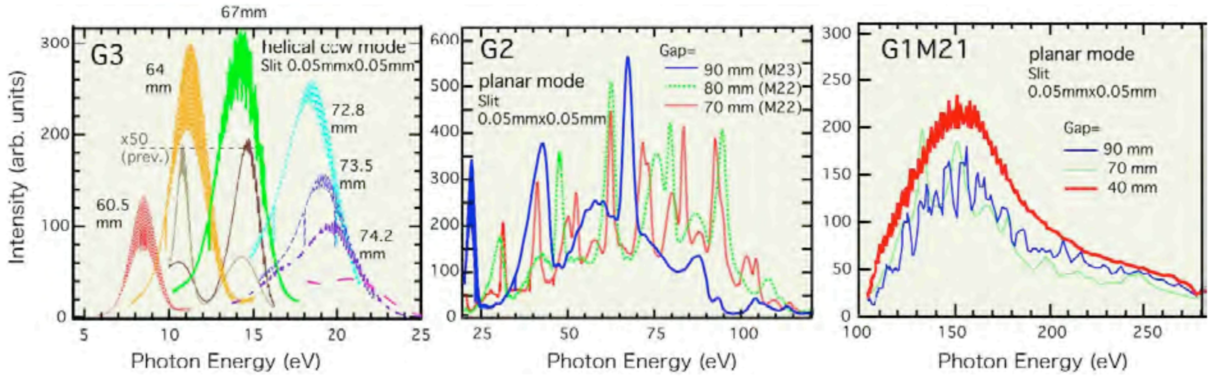

FIGURE 3. Throughput spectra from the SGM-TRAIN at BL5U after the reconstruction. The spectra before the reconstruction in the G3 region are also plotted [4].

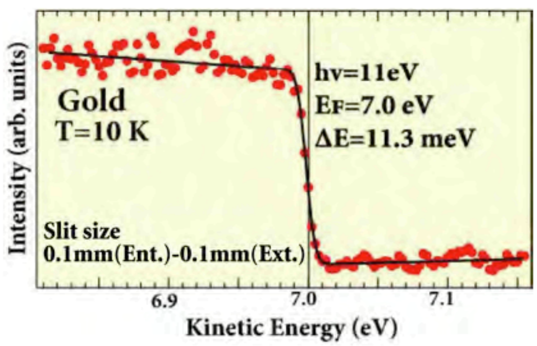

FIGURE 4. HRPES spectrum at the Fermi level of gold measured after the present reconstruction.

THE RECONSTRUCTION OF THE MONOCHROMATOR, "SGM-TRAIN"

To perform a high energy-resolution 3D-ARPES, both of the high energy-resolution and high photon-flux are necessary. The undulator provides the high photon-flux, while the high energy-resolution has been insufficient because of the problems with the monochromator. At the first stage of the beamline construction, the SGM-TRAIN, designed as keeping the Rowland mount similar to the Dragon-type monochromator [4], was aligned to the bending-magnet radiation [5]. It should be noted here that the undulator source has been used only for the free-electron-laser experiments before upgrading of the UVSOR [6]. After upgrading of the UVSOR, we planned to use the high-brilliant undulator radiation. Accordingly, some problems became known; (1) Mechanism for optimizing the pre-focusing mirror was too rough for the undulator light. (2) Entrance slit must be cooled against the higher heat load than the bending magnet radiation. (3) The grating G3 with normal incident mount for the low energy-region ($h\nu = 5\sim25$ eV), which is important for the high-energy resolution as well as a bulk-sensitive photoemission, had not been optimized [7]. These problems came from the design-concept of the beamline BL5U, which has been used for the core-level and valence-band photoemission spectroscopy, where the required energy-range (> 30 eV) could be covered with the other two gratings G1 and G2. Then we reconstructed and optimized BL5U as following to improve the efficiency in the low-energy range, to perform 3D-ARPES experiment.

Figure 3 shows the improved throughput from the SGM-TRAIN after the present reconstruction in comparison with the previous throughput spectra. We can clearly find that the mesh current increases more than 50 times in the G3 region.The photon flux (N_{ph}) is evaluated to be about 10^{12} photons/sec in the energy resolution of $h\nu/\Delta h\nu\sim1000$. Note that the sharp oscillatory structure observed in the throughput spectra originates from the interference between two undulators locating at the upstream and downstream of one long straight-section of an optical klystron-type undulator (U5). Due to the high-throughput of the photocurrent at the low-energy region, the HRPES measurement at BL5U becomes available. For example, HRPES spectrum at the Fermi-level of gold (Fig. 4) has been corrected within 1 hour with the resolution of $h\nu/\Delta E \sim 1000$. Therefore the present reconstruction makes it possible to insight into the origin of the anomalous physical properties by using the high-resolution bulk-sensitive angle-resolved photoemission apparatus at UVSOR-II BL5U. Furthermore, we plan to construct a new 3D-ARPES beamline (BL7U) in the VUV region at UVSOR-II [8], to pioneer a photoemission frontier research. The beamline is expected to cover the energy region of 6 – 40 eV with 20,000$\leq h\nu/\Delta E \leq$60,000 and with $N_{ph} \geq 10^{11}$ photons/sec in 10^{-4} band width. After the construction of new 3D-ARPES beamline BL7U, two-types of 3D-ARPES endstations (BL5U and BL7U) will play complementary role each other; the reconstructed BL5U for general researches (ex. core-level, valence band PES, wide-energy range 3D-ARPES) with medium-resolution, while the new BL7U for special ones (ex. 3D-ARPES at around E_F) requireing extensively high-resolution.

CONCLUSION

In conclusion, we reconstructed the high-energy-resolution three-dimensional angle-resolved photoemission beamline. The beamline is equipped with a variable polarized undulator, the SGM-TRAIN monochromator and a 200-mm radius hemispherical photoelectron analyzer. After improvement of the monochromator, the beamline covers the very wide photon energy-range of 5 – 250 eV with the photoemission energy resolution of $h\nu/\Delta E \geq 1000$.

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