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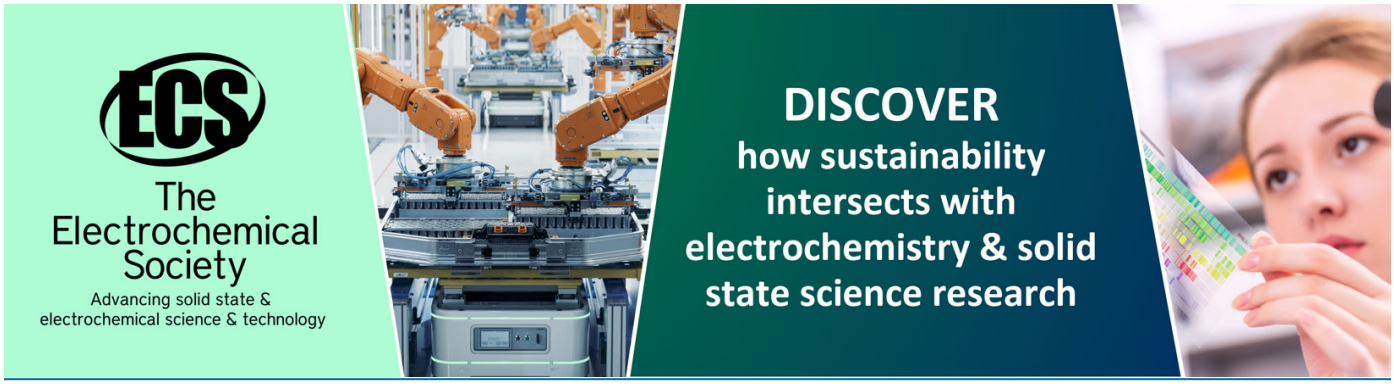

Journal of Physics: Conference Series **425** (2013) 152019 doi:10.1088/1742-6596/425/15/152019

Performance of PF BL-13A, a vacuum ultraviolet and soft X-ray undulator beamline for studying organic thin films adsorbed on surfaces

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Abstract. We report on the present status of a vacuum ultraviolet and soft X-ray undulator beamline, BL-13A, located at the Photon Factory. BL-13A is mainly dedicated to the study of organic thin films adsorbed on well-defined surfaces, using angle-resolved photoelectron spectroscopy (ARPES), X-ray photoelectron spectroscopy (XPS), and X-ray absorption spectroscopy (XAS). The photon-energy resolution ($E/\Delta E$) is estimated to be about 10000 at a photon energy of 64 eV with an exit-slit width of 30 μm. The photon intensity is estimated to be 2.9×10^{12} to 5.6×10^{8} photons/s for photon energies of 30–1600 eV with an exit-slit width of 100 μm at the ring current of 450 mA. An ultrahigh vacuum (UHV) chamber equipped with an electron-energy analyzer (Gamma Data/Scienta, SES 200) is used as the main end station for ARPES, XPS, and XAS measurements. A sample can be transferred from a UHV chamber for sample preparation or from a UHV chamber for the evaporation of organic materials. The sample-holder acceptors are equipped with a heating and cooling system. The overall electron-energy resolution is estimated to be about 12 meV at a photon energy of 30 eV.

1. Introduction

A vacuum ultraviolet and soft X-ray (VUV/SX) undulator beamline, BL-13A, located at the Photon Factory (PF), was made available to users on January 29, 2010. BL-13A is mainly dedicated to the study of organic thin films adsorbed on well-defined surfaces, using angle-resolved photoelectron spectroscopy (ARPES), X-ray photoelectron spectroscopy (XPS), and X-ray absorption spectroscopy (XAS). Details of BL-13A have been described in previous papers [1,2]. Briefly, BL-13A is an undulator-based VUV/SX beamline that adopts a variable-included-angle Monk-Gillieson-type monochromator with varied-line-spacing gratings (VLSGs) [3]. The center of a planar undulator [4] is regarded as the source point for the monochromator, and no entrance slit is used. BL-13A consists of a focusing pre-mirror (M1), a plane mirror (M2), two VLSGs, (300 and 1000 lines/mm), an exit slit, and two focusing post-mirrors (M3, 2-m:2-m focusing; M3′, 2-m:6-m focusing). The base pressure of BL-13A is maintained below 1×10^{-8} Pa to prevent contamination of the optics by residual gases. BL-13A suffered damage from the Great East Japan Earthquake on March 11, 2011 but was again made available to users on October 3, 2011. In this paper, we report on the present status of the BL-13A and the apparatus for ARPES, XPS, and XAS.

2. Photon-energy resolution and photon intensity

The advantage of the BL-13A is that both high photon-energy resolution and high photon intensity can be achieved simultaneously [1,3]. In the initial stage, the measured photon intensity was one order of magnitude lower than the calculated value [2]. We attributed the reduced photon intensity to the small acceptance angles in the measurements (ca. 0.06 mrad (vertical) × 0.2 mrad (horizontal)) and contamination of the optics. To address this, we increased the acceptance angles to ca. 0.4 mrad (vertical) × 0.27 mrad (horizontal) using a new quadruple mask [5] and we removed the carbon contamination of the optics using oxygen activated by 0th-order synchrotron radiation [6]. In this section, we report on the present photon-energy resolution and photon intensity. To estimate the photon-energy resolution ($E/\Delta E$), we measured the photoionization spectra of rare gasses (He, Ar, and Ne) and nitrogen (N_2) in four different photon-energy regions at about 64.1 eV (He), 244.4 eV (Ar), 401.1 eV (N_2), and 867.1 eV (Ne). The experiments were carried out in a chamber equipped with micro channel plates for ion detection at gas pressures between 1×10^{-4} and 1×10^{-5} Pa [2]. The photon intensity was measured by a silicon photodiode (AXUV-100, International Radiation Detectors, Inc.).

Figure 1 shows the 2, 1_4 and 2, 0_4 autoionizing resonances of doubly-excited He, measured with a 300 lines mm^{-1} VLSG with exit-slit widths of 30 and 100 μm. Assuming the natural lifetime widths to be 0.06 and 3.4 meV at autoionizing resonances of 2, 1_4 and 2, 0_4, respectively [7], we estimated $E/\Delta E$ to be 10000 and 6500 for exit-slit widths of 30 and 100 μm, respectively.

Figure 2 shows the photoionization spectra of Ar taken in the region of the $2p \rightarrow nl$ Rydberg transition with the 300 or 1000 lines mm^{-1} VLSGs with an exit-slit width of 30 or 100 μm. The $2p_{3/2} \rightarrow 4s$ peak at a photon energy of 244.39 eV was fitted using Voigt functions, where the natural lifetime width was taken to be 112 meV [8]. Using the Gaussian width obtained from the curve fitting, we estimated $E/\Delta E$ to be 3600 and 2900 for the 300 lines mm^{-1} VLSG with an

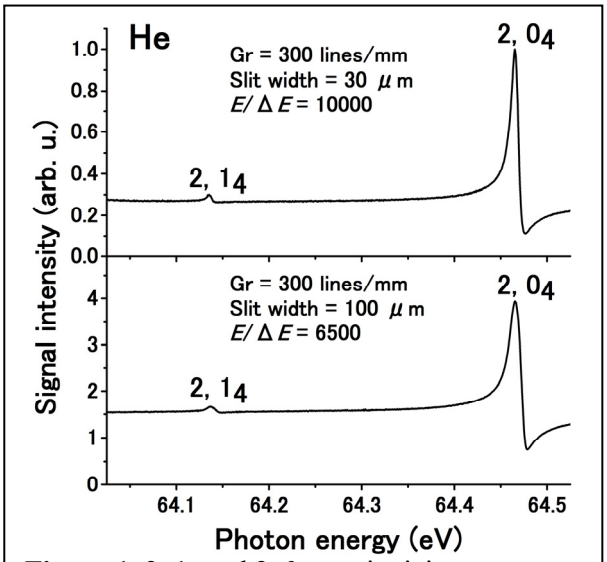

Figure 1. 2, 1_4 and 2, 0_4 autoionizing resonances of doubly-excited He.

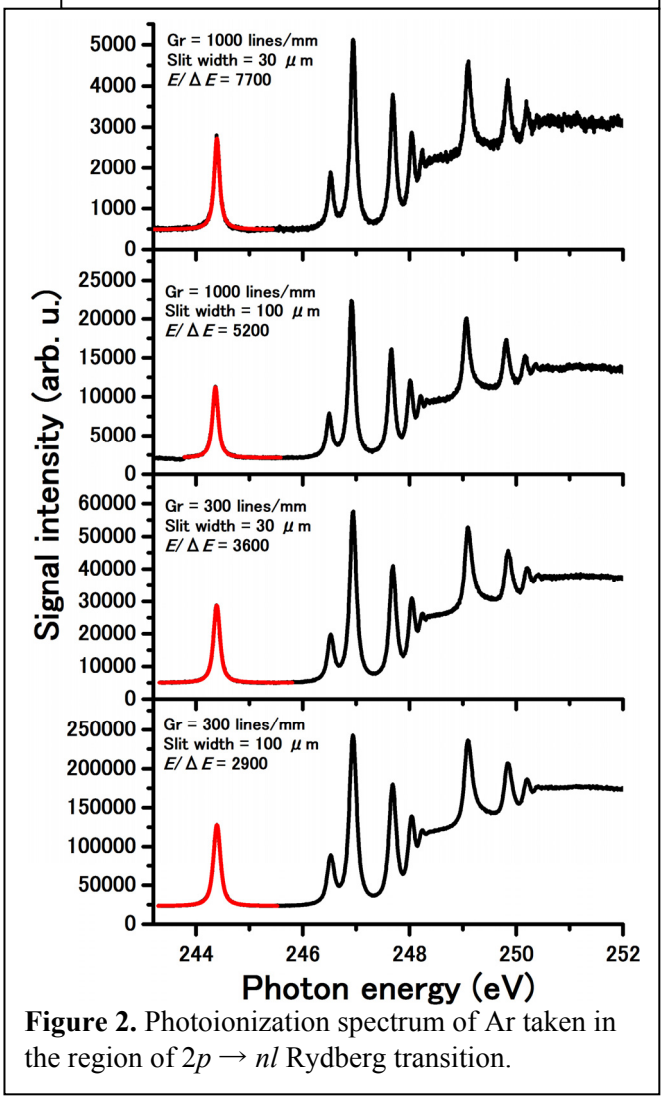

Figure 2. Photoionization spectrum of Ar taken in the region of $2p \rightarrow nl$ Rydberg transition.

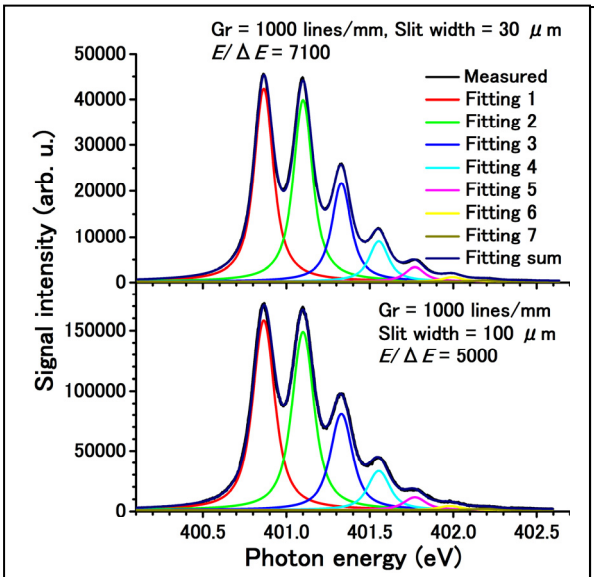

Figure 3. Photoionization spectrum of N_2 taken in the region of $1s \rightarrow \pi^*$ transition.

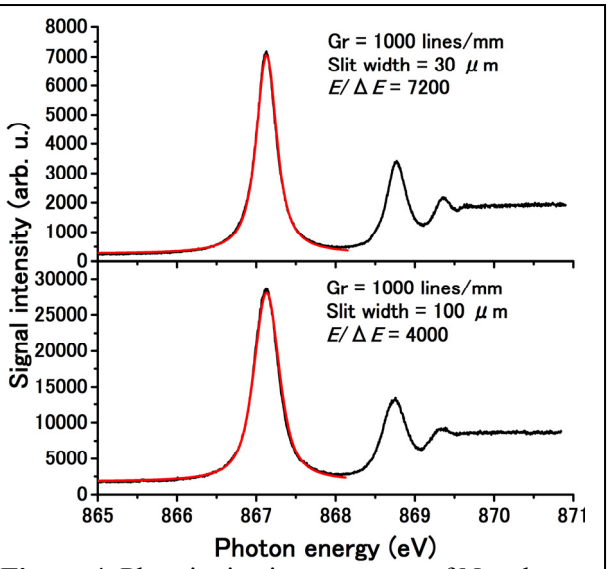

Figure 4. Photoionization spectrum of Ne taken in the region of $1s \rightarrow np$ transition.

exit-slit width of 30 and 100 μm, and 5200 and 7700 for the 1000 lines mm^{-1} VLSG with an exit-slit width of 30 and 100 μm, respectively.

Figure 3 shows the photoionization spectra of N_2 taken in the region of the $1s \rightarrow \pi^*$ transition with the 1000 lines mm^{-1} VLSGs with an exit-slit width of 30 and 100 μm. The peaks were fitted using Voigt functions, where the natural lifetime width was taken to be 113 meV [8]. Using the Gaussian width obtained from the curve fitting, we estimated $E/\Delta E$ to be 7100 and 5000 with an exit-slit width of 30 and 100 μm, respectively. The value for $E/\Delta E$ can be improved to 10000 when the acceptance angle is reduced to ca. 0.06 mrad (vertical) × 0.2 mrad (horizontal) [2]. The photon intensity, however, decreased to about 1×10^{10} photons/s under these conditions.

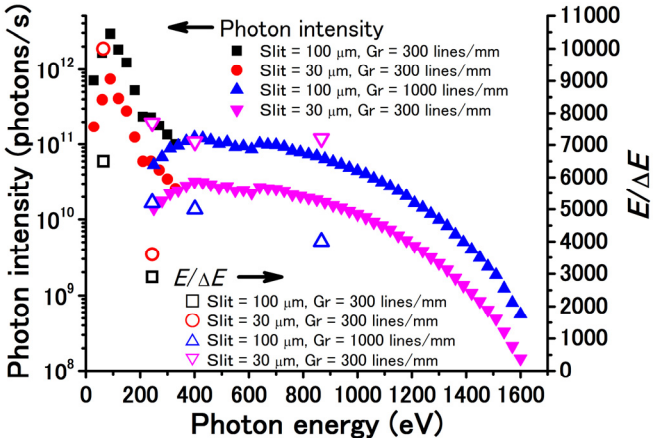

Figure 5. Summary of measured photon-energy resolutions ($E/\Delta E$) and photon intensities when the ring current is 450 mA.

Figure 4 shows the photoionization spectra of Ne taken in the region of the $1s \rightarrow np$ transition with the 1000 lines mm^{-1} VLSGs with an exit-slit width of 30 and 100 μm. The $1s \rightarrow 3p$ peak at a photon energy of 867.13 eV was fitted using a Voigt function, where the natural lifetime width was taken to be 252 meV [9]. Using the Gaussian width obtained from the curve fitting, we estimated $E/\Delta E$ to be 7200 and 4000 for an exit-slit width of 30 and 100 μm, respectively. The measured photon-energy resolutions and photon intensities when the ring current is 450 mA are summarized in Fig 5.

3. Apparatus for the study of organic thin films on surfaces using ARPES, XPS, and XAS

Figure 6 shows the apparatus used for the study of organic thin films adsorbed on well-defined surfaces using ARPES, XPS, and XAS. The apparatus consists of the main ultrahigh vacuum (UHV) chamber equipped with an electron-energy analyzer (Gamma Data/Scienta, SES200), a sample-preparation UHV chamber, and a UHV chamber for the evaporation of organic materials. The sample

can be transferred among UHV chambers with a transfer rod. The sample-holder acceptors in the main and sample-preparation chambers are both equipped with a sample heating and cooling system, as shown in Fig. 7. To estimate the overall electron-energy resolution, we measured a series of electron spectra in the Fermi region of an evaporated gold film at 5–9 K. We fitted the spectra with a convolution of a Fermi function and a Gaussian, and estimated the overall electron-energy resolution from the Gaussian width, as shown in Fig. 8. The best overall electron-energy resolution was about 12 meV at a photon energy of 30 eV.

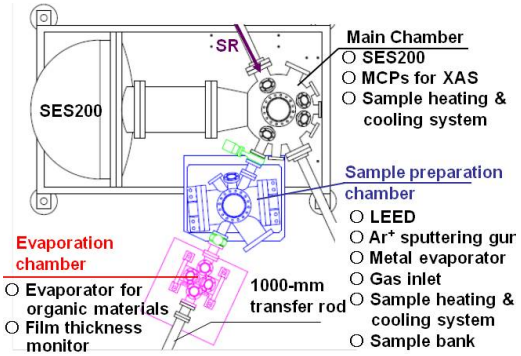

Figure 6. Apparatus for studying organic thin films adsorbed on well-defined surfaces using ARPES, XPS, and XAS.

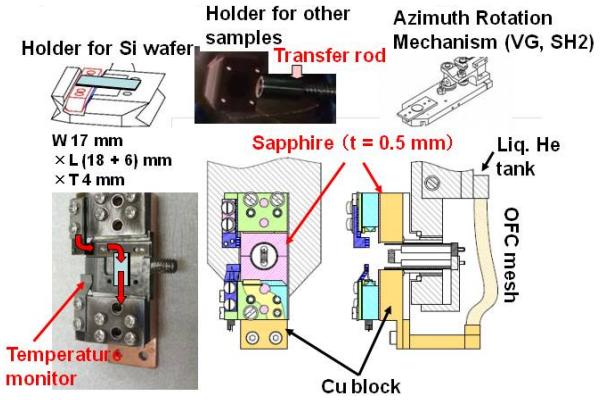

Figure 7. Sample holders and sample-holder acceptor.

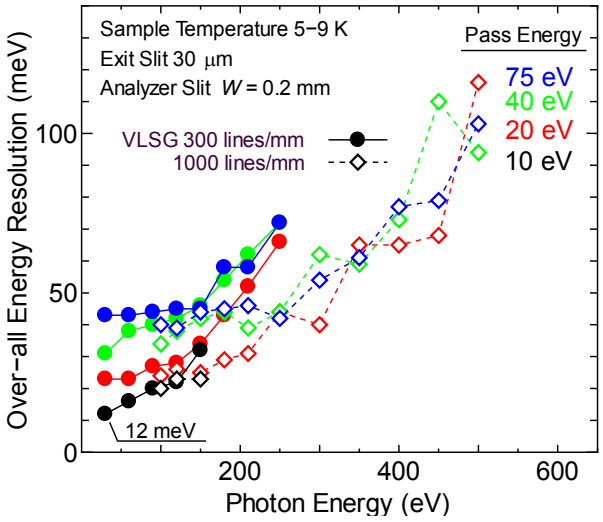

Figure 8. Overall electron-energy resolution as estimated with an electron-energy analyzer and an evaporated gold film at 5–9 K.

Acknowledgments

The authors are grateful to the users for their contribution to the construction of the apparatus. We also express our sincere thanks to the staff of PF for their support in conducting the performance evaluation of BL-13A.

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