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A compact vacuum-ultraviolet beamline for synchrotron radiation photoelectron spectroscopy combined with an ion-scattering spectrometer, SORIS

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Apparatus for high-resolution synchrotron radiation photoelectron spectroscopy combined with high-resolution medium-energy ion scattering, named 'SORIS', has been developed for simultaneous investigations of electronic states and atomic structures on surfaces. For this purpose, a compact vacuum-ultraviolet beamline of photon energy from 5 to 700 eV has been designed for the small storage ring 'Aurora' installed at Ritsumeikan University. Owing to the small electron-beam size in the storage ring, an energy resolution E/dE of >5000 can be obtained.

Keywords: monochromators; beamlines; vacuum ultraviolet; varied-space gratings; photoelectron spectroscopy.

1. Introduction

In surface science, simultaneous measurements of electronic states and atomic structures are quite important for accurate and precise interpretation of experimental data. In the present case, we chose photoelectron spectroscopy (PES) excited by synchrotron radiation (SR) and medium-energy ion-scattering spectroscopy (MEIS) for electronic states and atomic structures on surfaces, respectively. Installing large apparatus composed of both experimental systems at a beamline in a national SR facility is very difficult, because of the use of the beamline by many different types of SR user. This problem can be solved, owing to recent technical progress, by the use of a small electron storage ring, because SR can be used as a laboratory-scale light source installed on the university campus. This opens the way to new progress in SR science. In 1996, Ritsumeikan University installed the small storage ring named 'Aurora', developed by Sumitomo Heavy Industry Co. Ltd (Takahashi, 1987). SR from vacuum-ultraviolet (VUV) to soft X-ray is supplied by Aurora. In the experimental hall where the Aurora ring was installed, the space for beamlines and measurement apparatus was very limited. Because of this size problem, the high-resolution VUV beamlines reported for giant storage rings are not suitable for the present case (Petersen, 1995; Chen, 1987; Ishiguro *et al.*, 1989). Hence a new design of a compact beamline for a small storage ring had to be developed.

We constructed a novel experimental system named 'SORIS', composed of SR-PES and MEIS apparatus for surface studies at BL8 in the SR Center, Ritsumeikan University. In this paper, we report the design and the results of the performance tests of the beamline.

2. Layout of SORIS

The photon energy range of the beamline is from 5 to 700 eV, in which PES from ultraviolet to soft X-ray and X-ray absorption fine structure of C, N and O can be measured. Since the vertical size of the electron beam in the storage ring is small ($s = 0.14$ mm), a grazing-incidence monochromator with no entrance slit was chosen for the beamline. Another important choice was to use a varied-space grating as a dispersion element. In previous reports on the varied-space grating monochromator (Hettrick & Bowyer, 1983; Itoh *et al.*, 1989), it is found that a focusing element between the grating and the exit slit can be omitted. These two decisions saved space for the present beamline. Fig. 1 shows the layout of the optical elements of the beamline. The distance from the source point of the SR to the sample for PES is 9.1 m. The interval of the neighboring beam ports at the periphery of the storage ring is only 0.7 m. A large space at the end of the beamline must be kept for installing a MEIS system. A beam of SR with the rectangle shape of 3 (vertical) × 10.5 (horizontal) mrad impinges on a water-cooled cylindrical mirror, M0, made from a silicon single crystal. By this mirror, SR is horizontally focused on the exit slit. Then, SR reflected by the plane mirror M1 impinges on one of two varied-space plane gratings (VSPGs), G, of 400 and 1800 lines mm^{-1} (Hitachi, mechanically ruled original grating). One of two gratings is selected depending upon the photon energy. The grating is rotated around the center of the surface. The center of rotation of M1 is not on the mirror, but near the center of G. In this design, SR reflected by M1 can always hit the center of the grating surface. As M1 is rotated, the incident point of SR on the mirror is

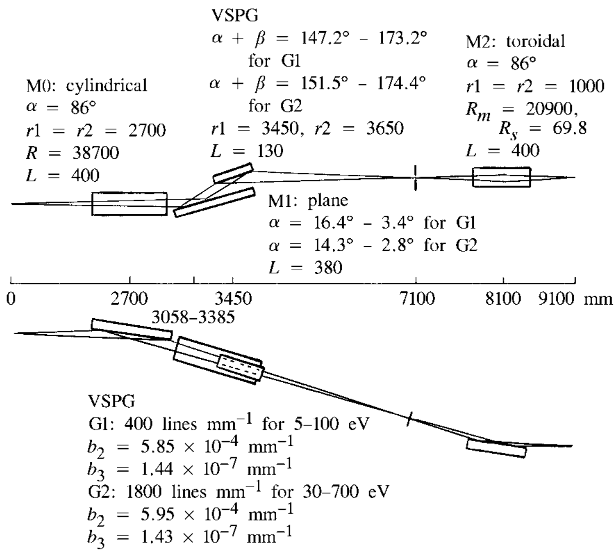

Figure 1
The layout and the optical parameters of the beamline of the SORIS system. M0: cylindrical mirror; M1: plane mirror; G1 and G2: varied-space plane gratings (VSPGs); M2: toroidal mirror; α and β: angles between the SR and optical elements; $r1$ and $r2$: distances; R: radius of mirror surface; L: length of optical elements. For G, $b2$ and $b3$ are the line-space variation parameters of the grating.

shifted from left to right or *vice versa*. Dispersed light from the grating is focused on the exit slit. Monochromatized light passing through the slit is focused by the toroidal mirror M2 on a sample. The photon flux is monitored by measuring photocurrent from a metal mesh put between M2 and a sample. The beam position at the sample is kept constant, independent from the photon energy, and the beam size is 1 (vertical) $\times$ 2 (horizontal) mm. The energy resolution and the photon flux on the sample estimated from ray-trace calculations are listed in Table 1. In order to calculate the transmission, which is equal to the ratio of the number of rays transmitted through the beamline optics to the total number of rays emitted from the source (5000 rays in the present calculations), the reflectivity of each mirror was estimated to be from 80% at the photon energy of 100 eV to 28% at 500 eV. The diffraction efficiency of the grating was assumed to be 10% over the whole range of the photon energy. The energy resolution of 0.3 eV can be obtained at the photon energy of 500 eV, which is near the ionization energy of an O 1*s* electron. The energy resolution $E/\mathrm{d}E$ over 5000 can be calculated at the low photon energy. The photon flux on the sample is of the order of 10^{11} photons s^{-1} (300 mA)$^{-1}$, which is satisfactory for many PES experiments.

Table 1
The results of the ray-trace calculation of the beamline shown in Fig. 1.

The low-line-density grating was used for calculation at the photon energy below 40 eV. Above 100 eV, the high-line-density grating was used.

Photon energy (eV)	Resolution $E/\mathrm{d}E$	Transmission (%)	Photon flux [photons s^{-1} (300 mA)$^{-1}$]
5	5500	2.1	3.40×10^{10}
20	3800	4.5	1.10×10^{11}
40	2800	10	3.40×10^{11}
100	3300	16.6	6.00×10^{11}
500	1700	0.49	1.80×10^{10}
700	1500	0.33	1.00×10^{10}

3. Optical characteristics

The whole beamline is evacuated to 1×10^{-8} Pa. The optical characteristics of the beamline were evaluated by the measurements of the photoelectron spectra and the photoelectric current from a clean sample of Au. Photoelectron spectra were measured by a high-resolution hemispherical electrostatic analyser (PHI, model 10–360 Omuni Focus III). No apparatus for gas absorption measurements for optical tests has yet been prepared in this research center. Fig. 2 shows the spectrum of the photoelectric current from Au in the photon energy range covered by the grating of 400 lines mm^{-1}. The peak current is about 6 nA. Two dips found at the photon energy of about 90 eV are due to photoabsorption by Au 4*f* electrons. Fig. 3 shows the photoelectron spectrum of Au measured at moderate energy resolutions of the electron spectrometer and the monochromator by the photon energy of 38 eV. The Fermi edge of the sample was clearly resolved and the large peaks due to 5*d* electrons were detected. The energy resolution of the beamline can be estimated by the narrowest experimental energy width of the electron distribution at the Fermi level. The experimental value is 60 meV at the optimum condition of the beamline. Taking account of the inherent width of the electron distribution at the Fermi level at room temperature (26 meV) and the energy resolution of the photoelectron spectrometer (about 40 meV), the resolution of the beamline was estimated to be 20 meV at the photon energy of 38 eV. As shown in Table 1, the result of ray tracing suggests 15 meV at the photon energy of 40 eV. The experimental resolution gives a good agreement with the calculated value. We therefore conclude that the present beamline gives satisfactory characteristics as compared with the ray-trace calculation in the photon energy range covered by the low-line-density grating. A high-line-density grating for the high photon energy is still being manufactured at present. Characteristics relating to PES and MEIS in SORIS will be published elsewhere [by Iwai *et al.* (1998) and Kido *et al.* (1998), respectively].

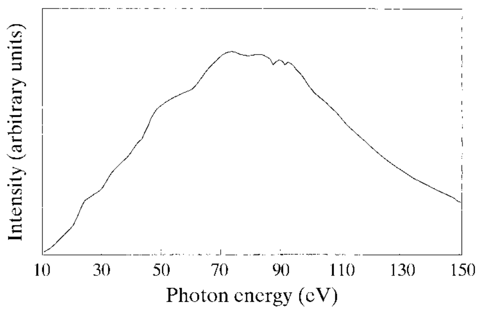

Figure 2
Spectrum of the photoelectric current from Au.

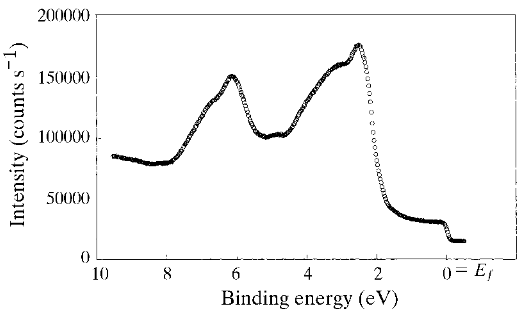

Figure 3
Photoelectron spectra of Au measured at a moderate resolution at the photon energy of 38 eV.

4. Conclusions

A compact beamline from 5 to 700 eV for photoelectron spectroscopy combined with medium-energy ion scattering on solid surfaces was developed for the small storage ring Aurora. It is confirmed that the combination of a small storage ring and a new design of beamline can give a high-quality SR light source close to the laboratory.

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