BL-11D/2011G661, 2013G702

Software for operating varied deviation-angle monochromator at BL-11D

Tadashi Hatano*
IMRAM, Tohoku University 980-8577, Japan

1 Introduction

The beamline BL-11D was used for photoemission measurements during 1996 – 2009 [1]. The monochromator was designed to cover 20 – 1300 eV energy range with a target resolving power of 5,000. It is composed of a cylindrical mirror Mf, a plane mirror Mp and a spherical grating G as shown in Fig. 1. G rotates around the center of its surface and Mp around the point C behind G. Monochromatization is achieved by suitable selection of Mp and G angles. It should be noticed that the footprint moves on Mp surface because of the off-center rotation of Mp. Gratings G1 and G3 are mounted for soft X-ray and VUV regions, respectively.

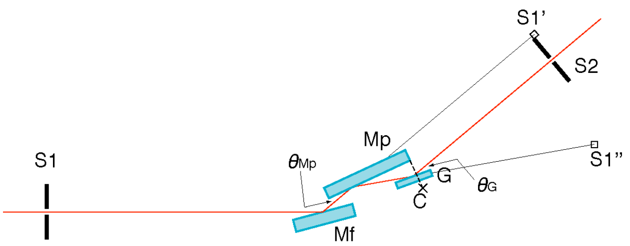

Fig. 1: Side view of monochromator optics of BL-11D.

In the previous operating software was based on the experimental data of photoelectron spectroscopy. Several Mp-G angle pairs that made spectral shape sharpest, were chosen to be fitted by fourth polynomial functions of photon energy. Consequently the monochromator did not work beyond the energy range where photoelectron experiments were performed. The operable range were 300 – 700 eV and 60 – 200 eV with G1 and G3, respectively [2].

Recently BL-11D was redesigned as a reflectometry beamline for VUV and soft X-ray curved mirrors. Spectral measurements are usually carried out with angle of incidence fixed. A new software was programmed for the purpose of extending the operable energy range including the dead zone of 200 – 300 eV. Transmission of thin films and absorption of gasses have been measured to confirm focus condition and energy calibration.

2 Theory

Above Mf, Mp and G geometry makes a negative incidence-length varied deviation-angle monochromator. It is similar to the Padmore type except for employing Mf which makes a convergent incidence to G. Without Mp, Mf makes an image of the entrance slit S1 at a fixed position S1'. The grazing angle of Mf is 2°, that is ∠S1-Mf-S1' = 176°. Mp makes an image of S1' at S1" which moves depending on the Mp angle θ_{Mp}. The origin of θ_{Mp} is taken to be the angle when the surface of Mp is parallel to the optical axis of Mf-S1'. The grazing angle of Mp agrees with θ_{Mp}.

The geometry of S1", G and the exit slit S2 determines the defocus and the wavelength. The optical axis from G to S2 is parallel to Mf-S1'. ∠S1"-G-S2, which agrees with the difference between 180° and the deviation angle $\alpha - \beta$, is a function of Mp and approximately equals $2\theta_{Mp}$ though the reflected optical axis does not exactly pass through the center of G. The negative incidence length r = –(G-S1") is also a function of θ_{Mp}. The distance r' = G-S2 is constant, and the diffraction angle β equals θ_G – 90°, where θ_G is the angle of G with the origin the angle when the surface of G parallel to G-S2. Quite simply, a 1° increase of θ_{Mp} makes a 2° decrease of α, and a 1° increase of θ_G makes 1° increases of both α and β. θ_{Mp} and θ_G changes the wavelength λ similarly but in the opposite direction.

Now the focus equation

$$\frac{\cos^2\alpha}{r} - \frac{\cos\alpha}{R} + \frac{\cos^2\beta}{r'} - \frac{\cos\beta}{R} = 0$$

and the grating equation

$$\sin\alpha + \sin\beta = \frac{\lambda}{\sigma}$$

can be written by parameters θ_{Mp}, θ_G. and λ, where R and σ are the radius of curvature and the groove constant of G, respectively. R is 55.21 m for G1 or 22.945 m for G3. The groove density σ^{-1} is 2400 *lines*/mm for both G1 and G3.

Although solutions for θ_{Mp} and θ_G should be obtained from a given λ in the practical monochromator use, it requires too complicated calculation. On the other hand, numerical solutions for θ_G and λ from a given θ_{Mp} is not difficult to obtain. Therefore a numerical list of θ_G and λ as a function of θ_{Mp} was prepared and an algorithm for selection of suitable θ_{Mp} and θ_G from a given λ by interpolation procedure was included in the monochromator operating software. Obtained θ_{Mp} and θ_{G} are plotted in Fig. 2 as functions of photon energy. The difference $\theta_{\mathrm{G}} - \theta_{\mathrm{Mp}}$, which approximately equals $\alpha + \beta$ is almost constant. It means that the blaze angle of G works over the whole energy range.

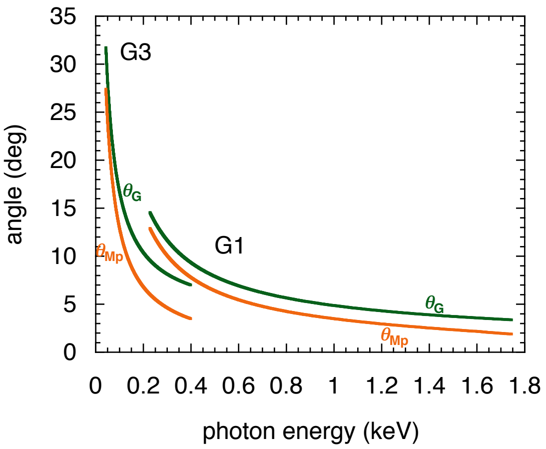

Fig. 2: Mp and G angles satisfying focus and grating equations.

3 Experiments

With a new monochromator operating software, spectral transmittances of Al, Si, Zr, Ti and C thin films were measured in 50 – 290 eV region using G3. Al-$L_{2,3}$, Si-$L_{2,3}$, Zr-$M_{4,5}$ and C-K absorptions were observed. Because of second order diffraction constituent of the grating monochromator, Si-$L_{2,3}$ and Ti-$L_{2,3}$ absorptions were also observed around 50 eV and 230 eV, respectively. Energy difference between spectra through $w > 0$ and through $w < 0$ gives defocus, where w means the position on the grating surface. Therefore grating area resolved spectra were measured using the angle selection slit after the post focusing mirror.

Unexpected behavior was found on the focus, that is the focal point moves toward outside S2 as photon energy increases. It can not be interpreted as an error in radius of curvature of Mf or G. It seemed as if R had changed depending on energy. This problem was fixed when a surface deformation in a third polynomial function as shown in Fig. 3 was assumed with Mp. The reflection point which moves depending on the photon energy is shown by arrows. The minimum radius of curvature is 200 m. Possible other causes such as unsmooth rotation of Mp were also converted into the deformation parameters.

Kr-$M_{4,5}$ absorption was measured using an ion detector [3] mounted between the post-focusing mirror and the reflectometer. Results are shown in Fig. 4. The line structure was clearly observed.

Using G1, C-K, Zr-$M_{2,3}$ and $L_{2,3}$ absorptions of 3d transition metals were measured in 280 – 950 eV region. N-K absorption was measured at 401 eV. Spectral reflectometry experiments up to 1200 eV was carried out [2, 4]. As a result, it has been confirmed that the monochromator works in 230 – 1200 eV with G1.

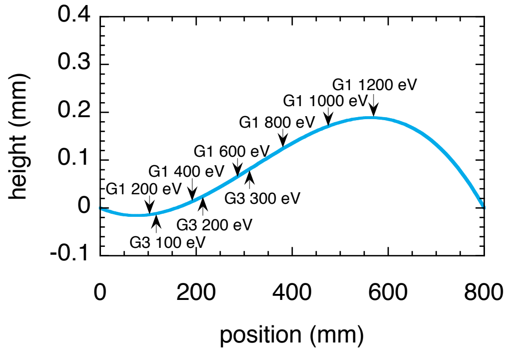

Fig. 3: Result of surface deformation analysis of Mp.

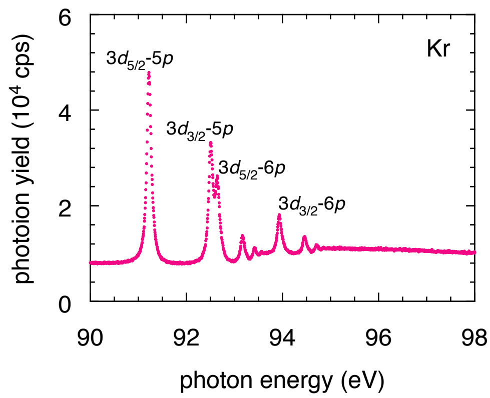

Fig. 4: Measured absorption spectrum of Kr.

4 Conclusions

The monochromator operation software at BL-11D has been renewed on the basis of no defocus condition to cover 60 – 1200 eV energy range.

Acknowledgement

The author is grateful to Mr. K. Watanabe for his LabVIEW programming. He is also grateful to Prof. K. Mase for his help in gas measurements.

References

[1] *PF Act. Rep. 1997 A*, **#15**, 101 (1998).
[2] T. Hatano et al., *J. Phys.: Conf. Ser.* **425**, 152018 (2013).
[3] N. Fujita et al., *J. Vac. Soc. Jpn.*, **50**, 583 (2007).
[4] T. Hatano et al., *J. Electron Spectrosc. Relat. Phenom.* **196**, 156 (2014).

* hatano@tagen.tohoku.ac.jp