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A simple accurate method of alignment of beamline optics with the use of EUV multilayer polarizers

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A simple alignment method is proposed, which enables the alignment of beamline optics of a bending section accurately, relying on the linear state of polarization of synchrotron orbital radiation rather than the beam intensity. The method utilizes extreme UV (EUV) multilayers as a compact polarization monitor detecting unwanted vertical polarization components. The proposed method was found to be far more sensitive than that relying on the maximum intensity. Another advantage is the insensitivity to surface contamination, such as an irradiation mark on the mirror degrading reflectance. A design example is presented for use around a photon energy of 370 eV along with an experimental example at a photon energy of 97 eV.

Keywords: extreme UV (EUV); polarization monitor; multilayer mirror; polarizer.

1. Introduction

At a beamline of a bending section, most users assume that the synchrotron orbital radiation (synchrotron radiation) beam is linearly polarized with its plane of vibration being horizontal. This is true only if the beamline optics, particularly the first steering mirror adjusting the elevation angle of the beam, are aligned correctly. A standard method of alignment is to adjust the relevant mirror deflection so as to obtain the maximum beam intensity. This method was found to be insufficient for beamline 11A at the Photon Factory (PF), KEK, owing to deterioration of the mirror reflectivity by contamination deposition upon synchrotron radiation irradiation. In such a case, as we align the first mirror for the maximum intensity, the state of polarization of the beam deviates from the ideal linear polarization to elliptical with its azimuth inclined, according to our findings by polarization measurements using multilayer polarizing elements (Kimura *et al.*, 1990). The same type of polarization variations were observed at some other beamlines of PF, KEK, and have been explained basically by the relative phase shift between *p*- and *s*-polarizations upon total reflection at the mirrors of the beamline optics, combined with some misalignments (Kimura *et al.*, 1993). These findings raise a problem in alignment common to well used beamlines as their optics have been used for long periods.

In the process of evaluation of EUV multilayer polarizers used in these experiments, we found the use of the polarizer to be very effective in discovering the best aligned position at which the best linear polarization was obtained. In this paper, we propose a simple and accurate alignment method for beamline optics using EUV multilayer polarizers. After a brief explanation of the polarizers, a design example of a polarizer at a photon energy of 370 eV will be described to depict basic characteristics through dependencies on the angle of incidence and the photon energy of the synchrotron radiation beam. Then, with a schematic view of the proposed equipment, experimental results at a photon energy of 97 eV will be presented, which well support the high accuracy to be discussed in the last section.

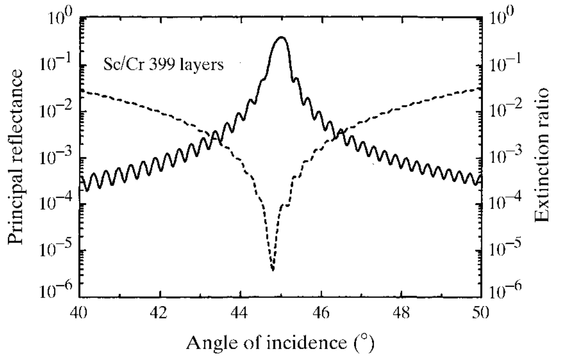

Figure 1
The principal reflectance (solid curve) and the extinction ratio (dashed curve) of a multilayer reflection polarizer calculated at a photon energy of 368 eV. The multilayer is assumed to be composed of 199.5 periods of a 14.5 Å thick Sc layer and a 9.5 Å thick Cr layer alternated as a pair. The multilayer is expected to be a polarizer at an angle of incidence between 42 and 47° with an extinction ratio better than 0.01.

2. Multilayer polarizing elements

EUV multilayer mirrors utilize constructive interference by multilayer structures composed of alternative ultra-thin layers of two materials of good optical contrast. Since the optical constants of the materials are close to 1, the pseudo-Brewster angles of the interfaces are close to 45°, around which the reflectance of the multilayers for the *p*-polarization decreases to the minimum, whereas that for the *s*-polarization can be enhanced by the constructive interference. Both the principal transmittance and the extinction ratio characterizing a polarizer are good enough for a single reflection polarizer for various polarization measurements, including thin film ellipsometry, having confirmed the relative phase shift upon total reflection (Yamamoto *et al.*, 1996).

In addition to the polarizer, phase plates of large retardations, such as λ/4 and λ/2 plates, have been realized (Nomura *et al.*, 1992) using transmission multilayers prepared as a free-standing type with their substrate removed, as proposed by Kortright & Underwood (1990). These polarizing elements were composed of periodical stacks of Mo and Si layers, which show high performance at a photon energy from around 80 eV up to 98 eV, the *L* absorption edge of Si.

At the higher photon energy region up to 700 eV, multilayer polarizing elements have been proved to be useful, in spite of a relatively poor performance, for polarization evaluation of synchrotron radiation at ALS (Kortright *et al.*, 1996) and BESSY (Di Fonzo *et al.*, 1995), as well as for magneto Kerr effect measurements (Kortright & Rice, 1996).

Fig. 1 shows a design example of such a multilayer polarizer for a photon energy of 368 eV. According to the materials selection criteria in terms of their optical constants (Yamamoto & Namioka, 1992), Sc and Cr are selected as the elements with small absorptions and with a good contrast in the refractive indices. This combination has been reported recently as the elements of the best normal incidence mirror of 10% reflectance at a wavelength of 3.14 nm (Salashchenko & Sharnov, 1996) and has high practical potential for polarizers.

According to our design, the optimum thicknesses for the maximum reflectance for *s*-polarization at the angle of incidence of 45° are 14.5 Å for Sc and 9.5 Å for Cr. With an ideally flat 399-layer structure, the principal transmission of this polarizer in terms of principal reflectance, which is equal to *s*-reflectance, *Rs*, is 40%, and the extinction ratio, which is equal to the reflectance ratio of *p*- and *s*-reflectances, *Rp*/*Rs*, reaches a good level below 10^{-4}. As seen in Fig. 1, the FWHM of the angle of incidence at the reflectance peak is 0.4°, which is large enough to accept synchrotron radiation from a beamline.

Fig. 2 shows calculated principal reflectance and extinction ratio spectra of the same multilayer at seven angles of incidence from 40 to 50°. The FWHM of the photon energy at each reflectance peak is around 0.3 eV, which is wide enough to deliver sufficient light for polarization monitoring. It is not shown in this figure, but reflectances on both sides of the peak are smaller by at least two orders of magnitude. The reflectance at 100 eV is 0.2% and the peak reflectance of the next interference order at 730 eV is 0.47%. Therefore, the multilayer polarizer suppresses stray light, including the overlapping higher-order light of a grating mono-chromator. This effect is due to the dispersion of the optical constant. An example of such suppression can be seen in Fig. 2 in the reflectance drop of the main peak above 400 eV, where the absorption of Sc layers increases.

In the extinction ratio spectra, interference structures around the reflectance peaks are evident although their amplitudes of variation are within one order of magnitude of the average values, *i.e.* the extinction ratio is stable regardless of the operational photon energy, but is largely dependent on the angle of incidence. Taking a level of the ratio below 0.01, any angle of incidence between 43 and 47° can be used for a polarizer. At the centre angle of incidence of 45°, a spectral range from 360 to 380 eV can be covered with the principal reflectance above 1% and the extinction ratio below 0.0001. By slight adjustment of the angle of incidence, a wider spectral range from 350 to 390 eV can be covered with the extinction ratio greater than 0.01.

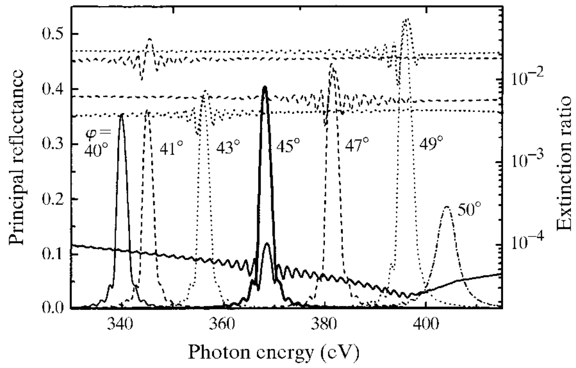

Figure 2
Angle of incidence dependence of the principal reflectance spectra and the extinction ratio spectra calculated with the same multilayer structure as shown in Fig. 1. The reflectance peak moves to higher photon energy as the angle of incidence increases. The extinction ratio is basically constant, regardless of the photon energy, although the values are strongly dependent on the angle of incidence.

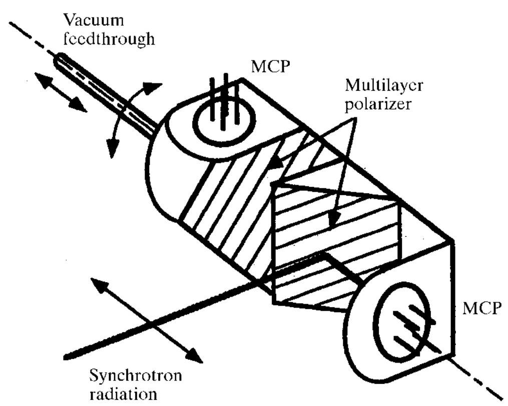

Figure 3
Schematic view of the proposed polarization monitor unit composed of two multilayer mirror polarizers and microchannel plates (MCP). At the extracted position shown, the polarizer is sensitive to the unwanted component of vertical vibration. By slight rotation of the vacuum feedthrough rod, the inclination of the azimuth of polarization ellipse can be compensated. The inserted position is used for preliminary alignments.

3. Linear polarization monitor

With the polarizers, a compact polarization monitor can be formed, as shown in Fig. 3. Two multilayer mirrors are mounted for detecting horizontal and vertical vibration components of synchrotron radiation. Microchannel plates are used as the detectors. The assembly is mounted on an ultrahigh vacuum feedthrough with linear motion to select the multilayer mirrors. The assembly is to be mounted downstream of a so-called I_0 intensity monitor of the beamline.

The alignment method is as follows. First, set in the inserted position for detection of the horizontal vibration components. Preliminary alignment should be performed in this position to avoid losing the beam. Then set the monitor in the extracted position, shown in Fig. 3, for detection of unwanted vertical vibration components. In this position, the signal ratio of I_m/I_0 should be the minimum with the optics aligned to the exact position where the beam delivered by the beamline is linearly polarized, with its plane of vibration horizontal. By slight rotation

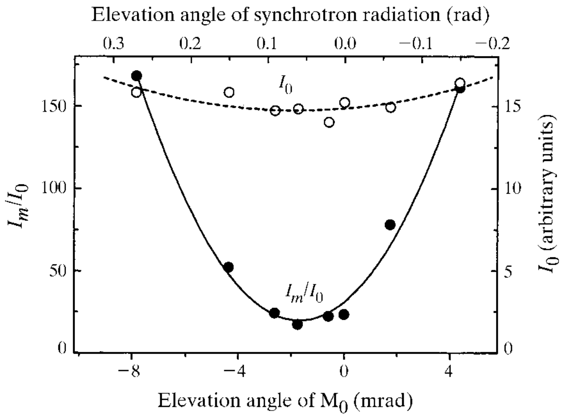

Figure 4
An experimental example of the alignment signal ratio I_m/I_0 (solid circles) and the output of the I_0 monitor composed of a gold mesh (dashed circles). The gentle minimum in I_0 is likely due to surface contamination of the mirror. Estimated by the fitting results, the proposed method is sensitive to 0.003 mrad of the elevation angle of synchrotron radiation.

of the feedthrough, a possible effect of inclination of the polarization can be compensated, if necessary.

An experimental result demonstrating this method is shown in Fig. 4. The experiment was carried out at PF beamline 11A. Since the details of the optical configuration of the beamline can be found in our previous publication (Kimura *et al.*, 1992), relevant optical elements are described briefly. In the beamline, the first vertical mirror, M_0, of which the surface normal is horizontal, serves to deliver the beam by total reflection at an angle of incidence of 88° to a horizontal mirror, M_1, of a 2-*m* grasshopper monochromator. Downstream of the monochromator, the beam intensity, I_0, monitor, composed of a gold mesh, is mounted.

In the experiment, the surface normal of the mirror M_0 was deflected vertically from a nominal value to vary the elevation angle of synchrotron radiation. In Fig. 4 the direct elevation angle of M_0, as estimated by the mechanically driven angle, is shown with the corresponding elevation angle of synchrotron radiation calculated for this configuration. During the experiments, variation of the optical path by the elevation of synchrotron radiation was compensated by adjusting the angle of incidence of M_1 so as to maintain the beam position at the entrance slit of the monochromator and deliver the beam of maximum intensity downstream at the output of the I_0 monitor.

The maximum output I_0 measured in this way was found to be almost stable, regardless of the elevation angle of M_0, with a gentle minimum likely due to contamination. On the other hand, the ratio of the polarizer monitor, I_m to I_0, shown by the solid circles, showed a deep valley centred at the elevation angle of −1.7 mrad, where the vertical vibration component of synchrotron radiation is minimum. Sensitivities of proposed and conventional methods estimated by the errors of fitting are 0.09 and 2.6 mrad of the elevation angle of M_0, respectively. The proposed method thus improves the sensitivity of alignment by a factor of 30 compared with the conventional method of intensity monitoring.

4. Discussion

The sensitivity improvement basically originates from the fact that the state of polarization of synchrotron radiation varies rapidly from left-circular to right-circular within the narrow range of the observation angle, typically a few mrad. The variation of intensity across the orbital plane, on the other hand, is very slow. The sensitivity of the proposed method is therefore dependent on the ring parameters and also the beamline optics involved. The essential limitation is the sensitivity of polarization detection, which is primarily limited by the extinction ratio E of the polarizer and also the degree of polarization of synchrotron radiation delivered.

By treating the unpolarized component as a residual ellipticity ϵ of the beam, the detection limit can be written in terms of either $E^{1/2}$ or ϵ, whichever is larger. With a multilayer polarizer of extinction ratio 0.0001, a residual ellipticity of 0.01 can be detected.

Although the state of polarization of the beam is affected primarily by the state of polarization of synchrotron radiation selected by the first mirror M_0, it is also affected by the amount of tilt of the planes of incidence of the following mirrors with respect to the exact horizontal or vertical plane. The tilt, when coupled with the relative phase shift upon total reflection, causes an inclination of the elliptical polarization in a particular manner, depending on the amount and direction of the tilt. By analysis with the knowledge of ellipsometry, we may simulate and analyse the polarization responses in more detail, which is beyond the scope of this report. In the meantime, it is enough to know that the alignment is accomplished by minimizing the observed ratio by slight movements of individual mirrors in turn until the deepest minimum is obtained, which is common practice in extinction ellipsometry. At the exact aligned position, the planes of incidence of mirrors lie horizontal or vertical, which causes no inclination of ellipse, regardless of the number of relative phase shifts.

It may be worth mentioning that the circular polarization monitor can be formed by mounting a multilayer transmission $\lambda/4$ plate in front with the appropriate azimuthal angle near 45° compensating the unequal *p*- and *s*-transmissions of the plate. In this configuration, two detectors give output for right- and left-circular polarizations.

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References

Di Fonzo, S., Muller, B. R., Jark, W., Gaupp, A., Schafers, F. & Underwood, J. H. (1995). *Rev. Sci. Instrum.* **66**, 1513–1517.

Kimura, H., Inoue, T., Maehara, T., Yamamoto, M., Yanagihara, M. & Namioka, T. (1990). *Prog. Book of Abstr. 15th Int. Conf. on X-ray and Inner-Shell Proc.* Knoxville, July 9, p. B08.

Kimura, H., Kinoshita, T., Suzuki, S., Miyahara, T. & Yamamoto, M. (1993). *Proc. Soc. Photo-Opt. Instrum. Eng.* **2010**, 37–44.

Kimura, H., Yamamoto, M., Yanagihara, M., Maehara, T. & Namioka, T. (1992). *Rev. Sci. Instrum.* **63**, 1379–1382.

Kortright, J. B. & Underwood, J. H. (1990). *Nucl. Instrum. Methods A*, **291**, 272–277.

Kortright, J. B. & Rice, M. (1996). *Proc. Photo-Opt. Instrum. Eng.* **2873**, 86–89.

Kortright, J. B., Rice, M., Hussain, Z., Padmore, H. A., Adamson, A., Huff, W. R. A., Young, A. T., Moler, J. E., Kellar, S. A., Ynzunza, R. X., Palomares, F. J., Daimon, H., Tober, E. D. & Fadley, C. S. (1996). *Rev. Sci. Instrum.* **67**, CD-ROM.

Nomura, H., Mayama, K., Sasaki, T., Yamamoto, M. & Yanagihara, M. (1992). *Proc. Soc. Photo-Opt. Instrum. Eng.* **1720**, 395–410.

Salashchenko, N. N. & Shamov, E. A. (1996). *Opt. Commun.* **134**, 7–10.

Yamamoto, M., Mayama, K., Kimura, H., Goto, Y. & Yanagihara, M. (1996). *J. Electron Spectrosc. Relat. Phenom.* **80**, 465–468.

Yamamoto, M. & Namioka, T. (1992). *Appl. Opt.* **31**, 1622–1630.