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Transmission multilayer polarizers for use in the 55–90 eV region

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Free-standing Al/YB$_6$ and Mo/Si transmission multilayer polarizers have been developed for use in the photon energy regions 55–72 eV and 72–90 eV, respectively, to improve the degree of polarization of synchrotron radiation light from beamline monochromators. The polarizance (polarizing ability) and transmittance of the Al/YB$_6$ multilayer for unpolarized light at 64 eV were 77% and 3.4%, respectively, and the polarizance and transmittance of the Mo/Si multilayer at 80 eV were 79% and 2.2%, respectively. By using the Mo/Si polarizer, the degree of polarization of the monochromated light at BL8B1 of UVSOR was increased from 95 to 99% in the 78–84 eV region.

Keywords: soft X-rays; polarizers; multilayers.

1. Introduction

An important application of soft X-ray multilayer polarizers is found in the study of magnetic rotation effects. Kortright *et al.* (1995) first reported Faraday rotation measurements around $L_{\rm II,III}$-edges of Fe with a reflection multilayer analyser using highly linear-polarized undulator radiation (98%) without a polarizer. To use bending-magnet radiation, however, a polarizer is required to improve the degree of polarization, which usually does not exceed 95%. In this study, we developed free-standing transmission multilayer polarizers in the 55–90 eV region to increase the degree of polarization of bending-magnet radiation for magnetic rotation experiments around $M_{\rm II,III}$-edges of 3*d* transition-metal elements. An obvious advantage of transmission multilayer polarizers is that they do not change the light path at any angle of incidence.

2. Discussion and results

Two Al/YB$_6$ polarizers for use around 55 and 64 eV and an Mo/Si polarizer for use around 80 eV were designed and fabricated using methods described in previous reports (Nomura *et al.*, 1992; Hu *et al.*, 1996). In Fig. 1(*a*), the smooth curves represent the calculated polarizance of the Al/YB$_6$ polarizer for 55 eV as a function of the angle of incidence at four photon energies between 52 and 59 eV. The polarizance of the polarizer, P_P, is defined by $P_P = (T_p - T_s)/(T_p + T_s)$, where T_p and T_s are the transmittances of *p*- and *s*-components, respectively. With this multilayer a polarizance above 90% could be achieved at any photon energy between 52 and 59 eV by setting the angle of incidence appropriately between 37 and 46°. By combining this polarizer with the Al/YB$_6$ polarizer for 64 eV and the Mo/Si polarizer for 80 eV, a set of polarizers with polarizance higher than 90% in the 55–90 eV region can be produced, as shown in Figs. 1(*b*) and 1(*c*). The calculated transmittances for unpolarized light $(T_p + T_s)/2$ at the photon energies of the polarizance maxima and the measured transmittances using our spectrometer equipped with a laser-produced-plasma source are given. The measured values (3.4% at 64 eV and 2.2% at 80 eV) were smaller than the calculated ones. At present, the reason for this is unknown.

The analysers used were reflection multilayers made by magnetron sputtering simultaneously with the transmission multilayers. The reflectance of the analyser for unpolarized light is expressed by $(R_s + R_p)/2$, where R_p and R_s are the reflectances of the *p*- and *s*-components, respectively. The calculated reflectances are given in Fig. 2 along with reflectances measured by the spectrometer. The measured reflectances were about 60% of the calculated ones. This seems to be due to the surface and interface roughness. In the case of reflection multilayers, the roughness does not decrease the polarizance drastically, so that in the following polarization analysis we assumed the polarizance of the analyser, $P_A = (R_s - R_p)/(R_s + R_p)$, to be the same as the calculated value given in Fig. 2.

The polarizances of the polarizers were measured at beamline BL8B1 of UVSOR as shown schematically in Fig. 3. The degree of polarization of the light passing through each polarizer was measured by an analyser unit, mounted with the same multilayer as that of the polarizer, which is rotated around the optical axis by the azimuthal angle φ_A. We can obtain the maximum polarization of the analyser by adjusting the angle of incidence θ_A *in situ.*

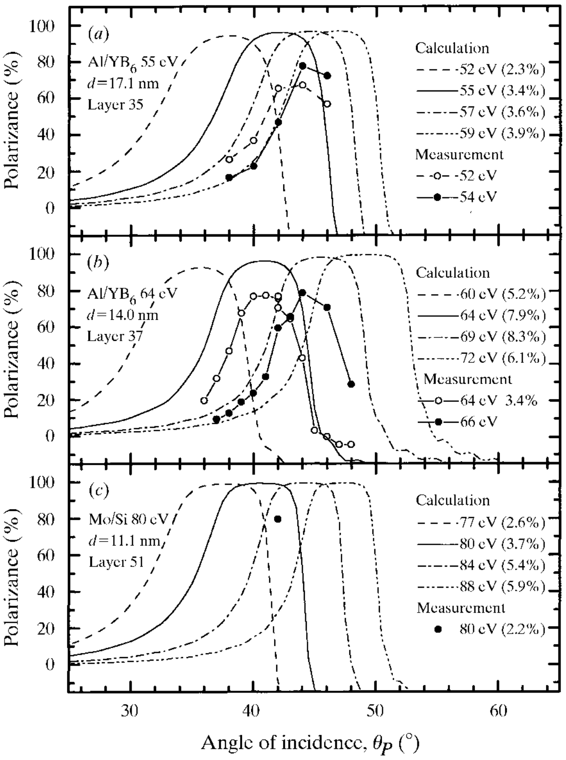

Figure 1
Calculated and measured polarizances of transmission multilayer polarizers as a function of angle of incidence: (*a*) Al/YB$_6$ for use around 55 eV, (*b*) Al/YB$_6$ for use around 64 eV and (*c*) Mo/Si for use around 80 eV. Figures in parentheses give transmittances at the angles of the maximum polarizance.

The degree of polarization of the synchrotron radiation, $P_{\rm SR}$, is defined as $P_{\rm SR} = (I_\pi - I_\sigma)/(I_\pi + I_\sigma)$, where I_σ and I_π are the intensities of the horizontal and vertical components, respectively. The polarizance measurements of the Al/YB$_6$ polarizers for 55 and 64 eV were made with the principal transmission axes rotated by 45° around the optical axis from the horizontal plane (φ_P = 135°). In this case, the throughput of the polarizer will be $(T_p + T_s)(I_\sigma + I_\pi)/2$, and the signal measured at φ_A = 135° (parallel orientation), $I_{135°}$, will be given by $I_{135°} = (R_pT_s + R_sT_p)(I_\sigma + I_\pi)/2$. The signal measured at $\varphi_{\rm A}$ = 45° (crossed orientation), $I_{45°}$, will be given by $I_{45°} = (R_pT_p + R_sT_s)(I_\sigma + I_\pi)/2$. Then we can obtain the contrast of signal intensities, $(I_{135°} - I_{45°})/(I_{135°} + I_{45°}) = P_AP_P$. Fig. 4 shows an example of the signals measured by the analyser unit, with the angles of incidence of the polarizer set at θ_P = 0° and θ_P = 42° at 64 eV. Similar measurements were made for various angles of incidence θ_P, and the polarizances evaluated by using the contrast equation are shown in Figs. 1(*a*) and 1(*b*). The maximum values for both Al/YB$_6$ polarizers were 77% at 54 and 64 eV.

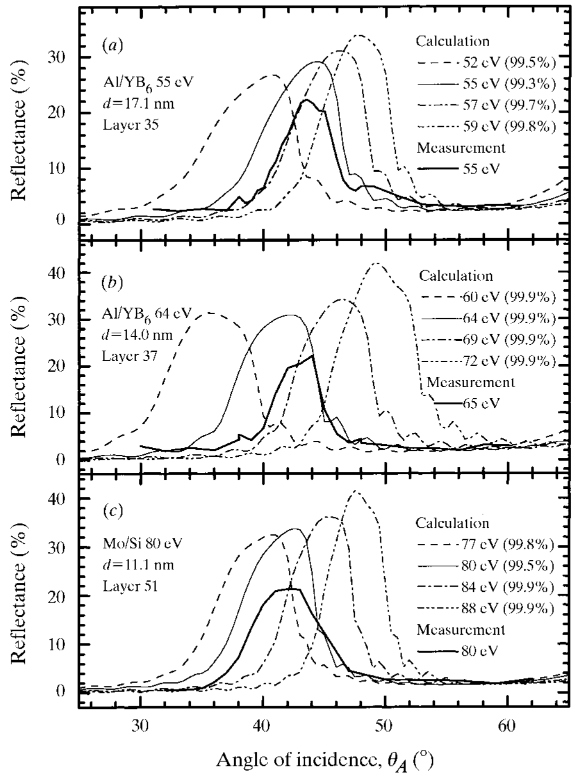

Figure 2

Calculated and measured reflectances of reflection multilayer analysers as a function of angle of incidence: (*a*) Al/YB$_6$ for use around 55 eV, (*b*) Al/YB$_6$ for use around 64 eV and (*c*) Mo/Si for use around 80 eV. Figures in parentheses give the maximum polarizances.

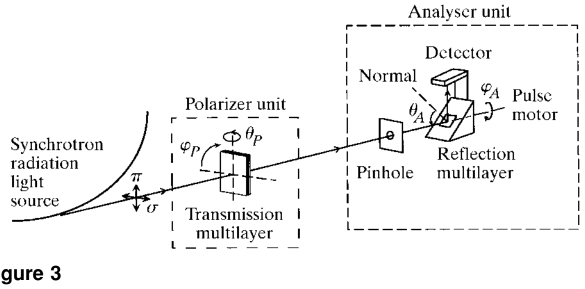

Figure 3

Schematic diagram of polarization measurement.

The polarizance measurements on the Mo/Si polarizer for 80 eV were made with the principal transmission axis set in the horizontal plane (φ_P = 0°). In this case, the throughput of the polarizer will be $T_pI_\sigma + T_sI_\pi$, the signal measured at φ_A = 0° (parallel orientation), $I_{0°}$, will be $R_sT_pI_\sigma + R_pT_sI_\pi$ and that at φ_A = 90° (crossed orientation), $I_{90°}$, will be $R_pT_pI_\sigma + R_sT_sI_\pi$. Then we can obtain the contrast of signal intensities $(I_{0°} - I_{90°})/(I_{0°} + I_{90°}) = P_A(P_{\rm SR} + P_P)/(1 + P_{\rm SR}P_P)$. When θ_P = 0°, the degree of polarization of the synchrotron radiation is obtained directly from the equation $P_{\rm SR} = (1/P_A)[(I_{0°} - I_{90°})/(I_{0°} + I_{90°})]$, because $P_P = 0$ at the normal incidence. After evaluating $P_{\rm SR}$, we can evaluate the polarizance P_P at any angle of incidence of the polarizer by using the contrast equation. Fig. 5 shows the degree of polarization of the synchrotron radiation and the evaluated polarizance of the polarizer at θ_P = 42°. The maximum polarizance for the Mo/Si polarizer was 79% at 80 eV. The original degree of polarization of the synchrotron radiation, given by open circles, was increased from 95 to 99% in the 78–84 eV region.

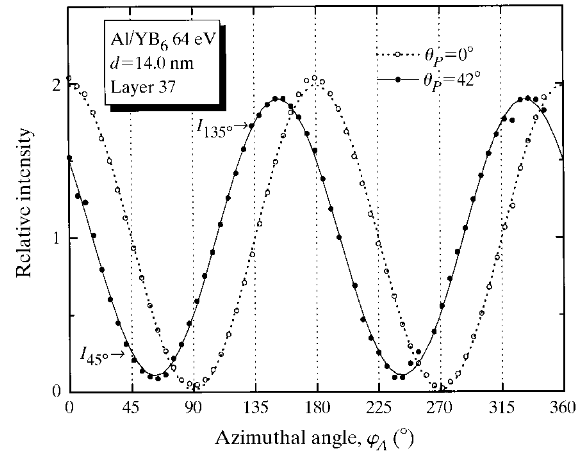

Figure 4

Signals from the analyser unit for monochromated light at 64 eV passing through an Al/YB$_6$ polarizer with its principal transmission axis rotated by φ_P = 135° from the horizontal plane plotted against φ_A. Open and closed circles give the signals at angles of incidence of the polarizer θ_P = 0° and 42°, respectively. Each signal is normalized so that the mean value of its maximum and minimum is 1.

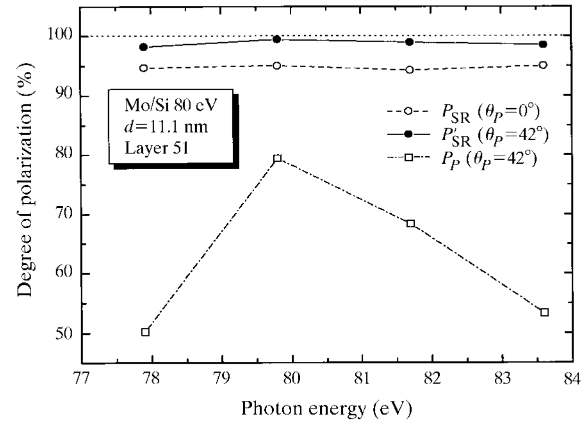

Figure 5

Degree of polarization of monochromated light at BL8B1 of UVSOR and polarizance of a Mo/Si transmission multilayer polarizer at angle of incidence θ_P = 42°. Open circles, closed circles and squares represent original degree of polarization ($P_{\rm SR}$), improved degree of polarization by the polarizer ($P'_{\rm SR}$) and polarizance of the polarizer (P_P), respectively.

The measured polarizances of the polarizers were about 80% of the calculated ones. Clarifying the reason for this and increasing the polarizance are future problems. For practical use, however, we should be able to undertake magnetic rotation experiments using the polarizers developed in the present work.

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