Polarization Measurement of 3W1B Beamline at BSRF in Soft X-Ray Range*

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Abstract Using Mo/Si multilayers as the polarizer and analyzer, we have measured the state of polarization for 86—89eV of Beamline 3W1B at Beijing Synchrotron Radiation Facility (BSRF). From the obtained data, we have determined the polarization parameters of Beamline 3W1B. Its polarizance is higher than 98% and the degree of circularly polarized radiation is between 1%—3% over a range of 86—89eV after polarizer.

Key words synchrotron radiation, polarization measurement, soft X-ray

1 Introduction

In recent years the interest in polarized light from synchrotron radiation source has increased in the soft X-ray (SXR) region particularly. Such as the X-ray magnetic circular- and linear-dichroism (XMCD, XMLD), which has been studied extensively in magnetic materials absorption and transmission[1, 2]. Resonant magnetic scattering of circularly and linearly polarized soft X-ray is another powerful technique for the study of the magneto-optical properties of materials and magnetically coupled multilayer structures[3]. Accurate evaluation of state of polarized light emerging from a monochromator is basically important. In the extreme ultraviolet region, traditionally, reflection polarizers are used. However, such polarizers lose their polarizing power for SXR because of grazing incidence essential to keep a reasonable throughput at these wavelengths and such mirrors set at the Brewster angle does not provide enough reflectivity to make effective use of it. Multilayer polarizers have been recently used, because a large ratio between the reflectances for the s and p component can be realized in the Brewster's angle. Dhez[4] measured the degree of linear polarization of synchrotron radiation from the ACO storage ring with a Hf/Si multilayer polarizer at 30.4nm and with a Nb/Si multilayer polarizer at 15.4nm. Kimura et al.[5] evaluated linearly the polarization degree of SR of wavelength 12.8nm emergent from a grasshopper monochromator at the Photon Factory using a Ru/Si multilayer. Recently, multilayer mirrors for SXR have been extensively developed, and they have been used widely in polarization measurement because of their excellent characters of high throughput and high polarizance in the vicinity of an 45° incidence angle for SXR. Two Mo/Si multilayers of the same characteristics are produced to make polarizers, one for a phase shifter and the other for an analyzer. Their reflectivities are more than 40% at 87eV.

In order to realize a full polarization measurement in SXR region, a polarimeter was made of these two

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identical reflection multilayers. We arranged two multilayer polarizers in the similar way to a double-crystal X-ray monochromator. Each of them was fixed at the incidence angle of 45°, so as to be able to work at Brewster angle. The analyzer can be rotated by means of a hand mechanism. The route of beam line was collimated so that the reflected radiation through double-multilayer polarizer could be received by Si diode.

For the first time, we have made the measurement of SR polarization in BSRF using homemade polarimeter. The degree of polarization of incident SXR and the ellipticity angle have been evaluated. The experiment and results are described in the following sections.

2 Analytical method

The description of analysis is based on the Stokes vector and the Mueller matrix formalism. The measured intensities of synchrotron radiation reflected by polarizers are $r_{\rm P}$ ($r_{\rm A}$ corresponding Analyzer), and induced phase shift $\Delta_{\rm P}(\Delta_{\rm A})$. The polarization of the light is described by the Stokes vector S=(S_0, S_1, S_2, S_3). S_0 is the total intensity of incidence light. S_1 presents linear polarization. S_2 presents linear polarization in a plane rotated by 45° degree with respect to the S_1 plane. S_3 is the circular polarization. Through the first polarization mirror, the total intensity of SR is described by S_0', and after analyzers that is presented by S_0''.

The experimental arrangement in our polarization measurement is shown in Fig. 1, where P is the phase-retarder (polarizer) and A is the analyzer. D is the Si diode detector. The analyzer A and the detector assembly D are rotatable about the reflected beam from P. Our polarization measurement requires independent rotation of both elements about the direction of light such that the polarization state is changed by the first and then analyzed by the second mirror. The χ and η defined the azimuthal angle of Polarizer and Analyzer, respectively. The two angles can be rotated along each incident optical axis. When azimuthal angle is fixed, whatever the altitude of Polarizer (Analyzer) is, the incident angle will not change.

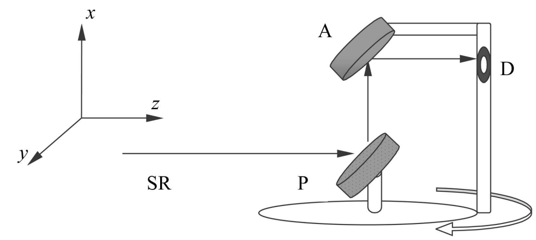

Fig. 1. Sketch of the measurement system used in our experiment.

The interaction of light with an optical element can be described by the Muller matrix $M_{\rm p}$ (α, $\Delta_{\rm P}$) for the phase shift and $M_{\rm A}$ (β, $\Delta_{\rm A}$) for analyzer[6].

$$M_{\rm P}(\alpha,\Delta)=\frac{r_{\rm pp}^2}{2}\begin{pmatrix}\alpha^2+1 & \alpha^2-1 & 0 & 0\\ \alpha^2-1 & \alpha^2+1 & 0 & 0\\ 0 & 0 & 2\alpha\cos\Delta & 2\alpha\sin\Delta\\ 0 & 0 & -2\alpha\sin\Delta & 2\alpha\cos\Delta\end{pmatrix}. \quad (1)$$

where $r_{\rm pp}$ is the reflectance of p component of SR by the phase shift, and α (β)=$r_{\rm s}/r_{\rm p}$ is a ratio of the amplitude reflectance of the polarizer (analyzer) for the s to p component. $\Delta=\Delta_{\rm p}-\Delta_{\rm s}$ is a retardation angle upon reflection for the two components. The azimuthal rotations correspond to a coordinate transformation given by the rotation matrix.

$$R(\chi,\eta)=\begin{pmatrix}1 & 0 & 0 & 0\\ 0 & \cos 2(\chi,\eta) & -\sin 2(\chi,\eta) & 0\\ 0 & \sin 2(\chi,\eta) & \cos 2(\chi,\eta) & 0\\ 0 & 0 & 0 & 1\end{pmatrix}. \quad (2)$$

After the light has been reflected by P and A and then reached D, its polarization is described by Stokes vector S_0'', which is a function of the Stokes vector of incident light S_0, the Muller matrices $M_{\rm P}$ (polarizer) and $M_{\rm A}$ (analyzer), and the rotation matrices $R(\chi)$ (polarizer) and $R(\eta)$ (analyzer). The intensity $I(\chi,\eta)$=S_0'' of the transmitted light is described as:

$$\begin{aligned}S_0''(\chi,\eta)=&\frac{r_{\rm PP}^2}{2}\cdot\frac{r_{\rm PA}^2}{2}\cdot((1+\alpha^2)(1+\beta^2)+(-1+\alpha^2)(-1+\beta^2)\cos 2\eta)S_0+S_2(((-1+\alpha^2)(1+\beta^2)+\\ &(1+\alpha^2)(-1+\beta^2)\cos 2\eta)\sin 2\chi+2(-1+\beta^2)\cos 2\chi\sin 2\eta\alpha\cos\Delta_{\rm P})+S_1(((-1+\alpha^2)(1+\beta^2)+\\ &(1+\alpha^2)(-1+\beta^2)\cos 2\eta)\cos 2\chi-2(-1+\beta^2)\sin 2\eta\sin 2\chi\alpha\cos\Delta_{\rm P})+2(-1+\beta^2)\sin 2\eta S_3\alpha\sin\Delta_{\rm P}. \quad (3)\end{aligned}$$

Eq. (3) includes four unknown Stokes vector of the incident light to be determined (S_0, S_1, S_2, S_3). Because only one phase-shifting Δ_p exists, the phase retardation of the analyzer Δ_A does not come into effect. By means of a least-square fit to the measured data, these unknown parameters of incident light can finally be determined.

3 Experiments

The experimental setup was installed in the vacuum chamber, which was designed for the optical elements. It was arranged downstream from the monochromator on the beam line of 3W1B. A 1.5T wiggler provided the radiation, and the energy ranges were covered from 50eV to 1500eV by a Various Space Plane Grating (VSPG) monochromater sysytem[7]. A 10nm Mo/Si multiplayer produced by magnetron sputtering was used as polarizer (P) and analyzer (A). Two multiplayer mirrors were mounted at ~45° angle of incidence. To evaluate the output of polarimeter, the intensity of the direct beam from the monochromator was measured between 70eV and 90eV with the detector D. Signals were collected by a silicon photodiode (AXUV-100G, IRD, USA) with a sensitive area of 10mm×10mm and a noise level less than 5pA, and indicated by electrometer (Model 6517, Kethley, USA)[8]. The polarization measurement was made for SXR from 86—89eV. At the range of 70—90eV, the energy resolution ($E/\Delta E$) was about 400. The azimuth angle of polarizer was fixed at 0° and 90°. The azimuth η of the analyzer was set manually in a range of rotation of $-4° < \eta < 184°$ to obtain a full 180° data. With the designed multilayer mirror, we have obtained significant increase in reflection around 45° as shown in Fig. 2(a).

With the special design, the maximum reflectivity of Mo/Si multiplayer (10nm) achieved 40% near Brewster angle, which made it adequate to obtain the better Signal-to-Noise rate. These multiplayer mirrors were assembled on the sample shelf as polarizers, whose polarizance were more than 98% between 40°—50° incident angle shown in Fig. 2(b). This polarization measurement has an independent rotation of both polarizer and analyzer around the direction of light. A fit to the transmitted intensity curve delivered the complete polarization state of the incoming synchrotron light.

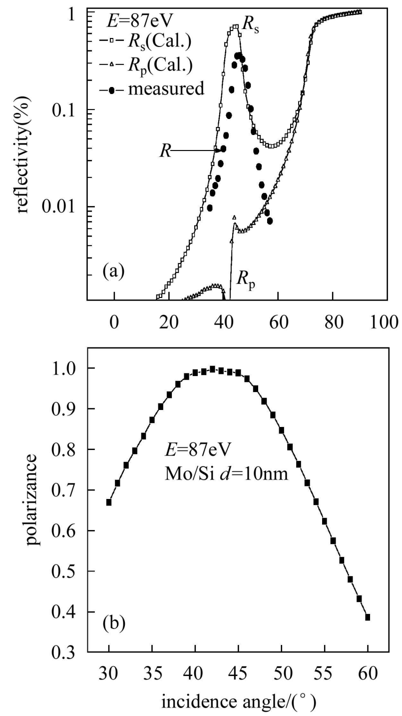

Fig. 2. (a) The simulated reflectance of two components (S and P) vs. measured reflectivity of Mo/Si soft X-ray multilayer; (b) The calculated polarizance of Mo/Si at 89eV can reach 99% between 40° and 46°.

4 Results and discussion

In this section measurement results are presented for a single photon energy, $h\nu$=87eV, Molybdenum/Silicon multilayers are used as polarizer and analyzer for this experiment because of their good reflection performance between the Mo N and Si L_{III} edges. By a rotation of analyser, a sinusoidal signal is observed. If we extend abscissa to 360°, a better direct result graph could be got. To compare with the design energy (equal to wavelength) of Mo/Si multilayer, the experiment was also carried out at other different photon energies near 87eV. Fig. 3 shows some examples of such signals plotted in logarithmic scale as a function of the analyser azimuth. All the signals are in the level of picoampere (pA).

In Fig.3 we used the usual Cartesian coordinates. Because the mirror is a wideband multilayer, similar results could be obtained between 86eV and 89eV. But those signals are less than the value of 87eV. When the signal reaches maximum value, the polarizer mirror is parallel to the analyzer mirror. In this state, the electronic vector of the parallel polarization of SR is perpendicular to the incident plane of mirrors and only the S component could be reflected completely. At the same time, the P component, which is perpendicular to the orbit plane has been restraining greatly. On the contrary, when the analyzer azimuth χ changed to 90 degree, the detected signal was devoted all by perpendicular polarization. Fig. 4(a) gives out the measurement results when χ equals 0° and 90°.

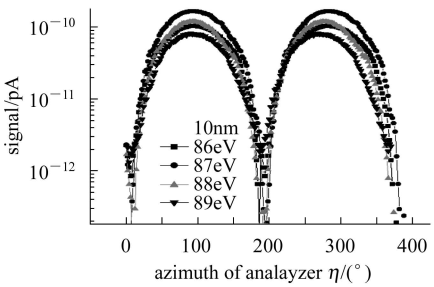

Fig. 3. Variation of the measurement signals achieved with different photon energies in a whole period. (Performance of the reflection multilayer as linear polarizer).

The symbols are the measurement result and the line is the fit curve by Eq. (3). When the azimuth angle of polarizer is 0°, the transmission light signal reaches 6.58×10^2 pA. Its relative signal passing two mirrors reflectivity is about 16%, and one polarizer is 40%, which is in fairly good agreement with the multilayer parameters measured before. Rotating polarizer's azimuth angle to the 90°, relative signal reflectivity declined from maximum 16% to 0.8%. For the ideal linear polarization SR, that would be close to zero when $\chi=90^\circ$. But in this experiment, the rotation angle is difficult to be control accurately all by hand. Fig. 4(b) shows the scanning results from 86eV to 89eV. The resulting Stokes parameters S_1, S_3 normalized to S_0 describing the linear and circular part of the incoming light are plotted. It seems that the energy odes not strongly influence the measured linearly polarization part in a little range. But the circular polarization depends sensitively upon the energy of incident soft X-ray. After fitting the measured data, the other correlative parameters of the incoming beam at 87eV are obtained. The Stokes parameters S_1/S_0=0.987, S_2/S_0=−0.07, and the degree of circularly polarization S_3/S_0=0.016. The ellipticity angle ε is 0.458 degree. Although the perpendicular e-beam divergence of 3W1 light source is about 0.599mrad, we can deduce that the incoming light emitted from the monochromator almost lies in the plane of the electronic orbit from the value S_1/S_0=0.987. It makes out that the good linear polarization can be achieved at the experimental station. However, there are also other places which need to be improved, such as the noises of data caused by the 6517 electrometer, the error brought by the rotation system and so on.

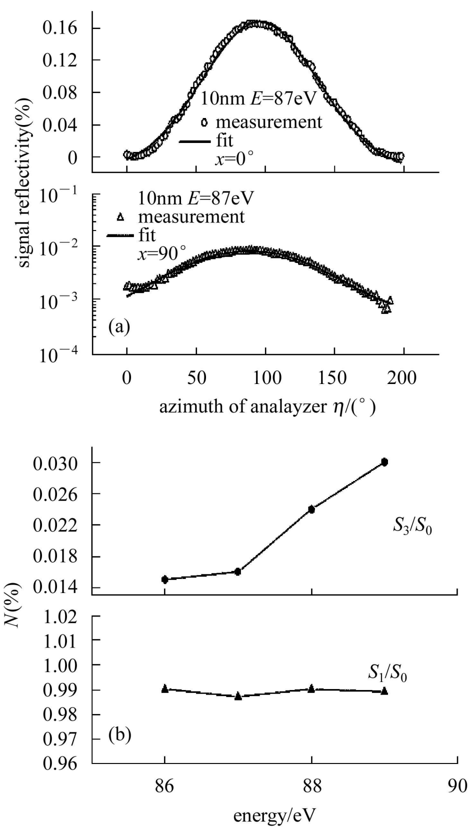

Fig. 4. (a) Intensity variation vs. azimuth angle of analyzer when $\chi = 0^\circ$ and $\chi = 90^\circ$; (b) Performance of the energy scanning for linear and circular polarization.

5 Summary

The polarization measurement equipment for soft X-ray has been installed at the BSRF. For the first time, the polarization of Beamline 3W1B has been measured in the soft X-ray range. The degree of the polarized light is more than 98%. It proves that the soft X-ray reaching the experimental station is good linearly polarized light, and that its circularly polarized component is less than 2%. The degree of the circular polarization increases gradually while the incidence light energy enhances. With the development of different multilayer mirrors, the polarization degree of other energies also can be obtained by our polarimeter. Further experiments on polarization measurement are expected to give out better parameters of the synchrotron radiation of soft X-ray in the near future.

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北京同步辐射装置3W1B软X射线光束线偏振特性测量*

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摘要 应用自行研制的Mo/Si周期多层膜作为起偏器和检偏器的光学元件, 测量了北京同步辐射装置3W1B束线的偏振状态. 通过数据分析, 得到了3W1B软X射线的有关偏振参数, 在86—89eV能区经过起偏器后的偏振度超过98%, 圆偏振分量介于1%—3%之间.

关键词 同步辐射 偏振测量 软X射线

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