# Performance of a polarizer using synthetic mica crystal in the 12–25 nm wavelength range*

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**Abstract:** To develop polarizer functioning in the extreme ultraviolet (EUV) and soft X-ray region, the polarization performance of synthetic mica has been investigated theoretically with a simulation code using Fresnel equations and optical constants from the Henke database. The reflectance of synthetic mica crystal for s and p polarization was measured to investigate its polarization performance in a home-made synchrotron radiation soft X-ray polarimeter at beamline 3W1B, Beijing Synchrotron Radiation Facility (BSRF). The reflectivity of the synthetic mica crystal at an angle of grazing incidence of 48° was obtained from the experimental data, which is about $4.8\times10^{-3}$ at 25 nm and $6.0\times10^{-4}$ at 12 nm, and the linear polarizance of the X-ray reflected by the synthetic mica crystal that we measured using an analyzer-rotating method increases from 80% to 96.6% in this EUV region, while higher than 98.2% in the simulation. The result indicates that this synthetic mica crystal works as a practical polarizer in this EUV region of 12–25 nm, and also in an extensive wavelength region higher than 25 nm.

**Key words:** synchrotron radiation, EUV, synthetic mica, polarization

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## 1 Introduction

Polarized radiations, including linearly and circularly polarized radiations, are becoming important and valuable in revealing the symmetry properties of atoms in the extreme ultraviolet (EUV) region, because the core atomic electrons could be ionized by an individual photon [1]. To use a bending-magnet (or wiggler) radiation, however, a polarizer or analyzer is required to improve the polarizance, which usually does not exceed 80%. In this EUV and soft X-ray region, high absorption is of vital importance in the interaction between the atom and the photon; this makes it difficult to find a polarizer or analyzer with high polarizance and reflectivity (or transmission). Recently, different polarization elements based on multilayers have been well developed. A linear analyzer based on a $Mo/B_4C/Si$ multilayer with almost 99.9% polarization and 70% s-component reflectivity at a wavelength of 13.5 nm has been realized [2]. A reflection-type polarization analyzer based on the broadband Mo/Si multilayer for the 15–17 nm wavelength range [3] and transmittance-type polarization analyzers of $Al/YB_{66}$ for 18–25 nm, Mo/Si for 14–16 nm [4] have been designed and manufactured before. All of the polarization elements above only work in a narrow wavelength range because of the restriction of the Bragg equation.

In addition to multilayer polarization elements, thin films and crystals are also used in the EUV and soft X-ray region. A triple-reflecting polarizer based on Au film was discussed in theory to work broadly in the wavelength range of 10–100 nm [5]. The synthetic mica crystal is also used at 1.3 nm (about 900 eV) at an incidence angle of 45° [6, 7]. Compared with a multilayer, polarization elements based on films and crystal are easily made and work well in a particular wavelength range in spite of lower reflectivity.

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Faraday rotation measurements around $L_{2,3}$ and $M_{2,3}$ edges of Fe, Co and Ni have been discussed before [8, 9], and they need in-depth research with an appropriate polarization element that can work in the wavelength region including the L and M absorption edges of Fe, Co and Ni. In this paper, the performance of a polarizer using mica crystal for the 12–25 nm wavelength range is calculated in theory and measured in experiment with synchrotron radiation. For the great development of a weak signal measurement in recent years, the synthetic mica crystal with low reflectance is firstly used as a polarizer in this wavelength range, and the polarizance is improved to 96.6% from 80%. Though the reflectivity of the synthetic mica is not high (0.06%–0.5%), the polarizance (about 96.6%) of the reflected X-ray from the synthetic mica is adaptable for magnetic-optical (MO) effect measurement at beamline 3W1B, Beijing Synchrotron Radiation Facility (BSRF).

## 2 Analog computation and analysis for synthetic mica

Synthetic mica (fluorophlogopite) and natural muscovite mica have a significant layer structure, and excellent thermal and chemical stability. Mica's chemical formal is $KMg_3(AlSi_3O_{10})F_2$ and its crystal system is monoclinic. The lattice constants are $a$=0.5308 nm, $b$=0.9183 nm, $c$=2.0278 nm and $\beta$=100.07° [10]. According to the chemical formula, using scattering factors of Henke [11] and Fresnel equations [12], we made a simulation code to evaluate the polarization performance of synthetic mica from 12 to 25 nm. The reflectivity calculated for s-, p-component X-ray and the polarizance of the synthetic mica are shown in Fig. 1. The reflectivities for s- ($R_s$) and p-component ($R_p$) X-rays increase from $6.4\times10^{-4}$ to $1.4\times10^{-2}$ and $4.9\times10^{-6}$ to $9\times10^{-5}$ with the wavelength from 12 nm to 25 nm, respectively. The contrast factor of mica ($R_s/R_p$) varies from 130 to 280 and the degree of polarization ($P_L=(R_s/R_p-1)/(R_s/R_p+1)$) is above 98.5% as a whole, while it reaches 99.3% at about 20 nm. It is obvious that both $R_s$ and $R_p$ are not high as a polarization element, but it can work in X-ray from bending-magnet synchrotron radiation for the recent great development of weak signal measurement.

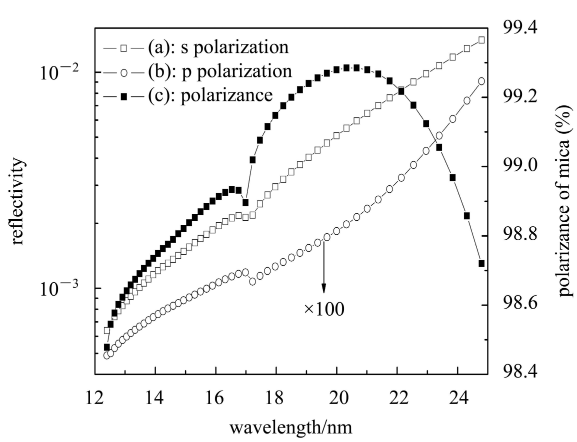


Fig. 1. The reflectivity of s-, p-component and the polarizance for synthetic mica (calculated value).

## 3 Experiments

The synthetic mica we used in this study is about 100 μm thick, and the component mainly follows the chemical formula with no more than 1% of some other elements, such as Ti, Cu, Nb.... To evaluate the crystallinity and lattice spacing of synthetic mica, the X-ray diffraction measurement was carried out using an X-ray diffractometer at the wavelength of the Cu $K_{\alpha1}$ emission band ($\lambda$=0.154 nm). The measuement results indicate that this sample maintains good crystallinity with lattice spacing of $d_{002}$=0.9984±0.0004 nm.

The measurement of the polarization performance of synthetic mica was carried out on a polarimeter with a grazing incidence angle of 48° The polarimeter is installed at Beamline 3W1B of BSRF [13]. The beamline is a windowless full UHV soft X-ray beamline utilizing a permanent-magnet wiggler source. It supplies focusing monochromatic soft X-rays. The

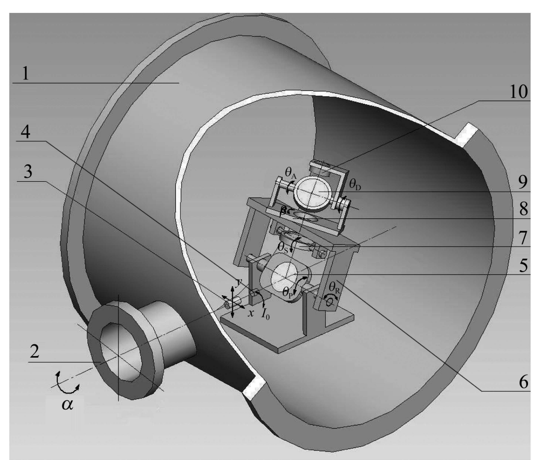


Fig. 2. A sketch map of the polarimeter. 1 chamber; 2 azimuthal angle $\alpha$ of polarizer; 3 collimator translation $x$-$y$ stage; 4 $I_0$ detector; 5 polarizer; 6 moving rocker; 7 sample stage; 8 rotational stage to change azimuth angle of analyzer; 9 analyzer; 10 main detector.

photon energy region is from 50 eV to 1600 eV. The chamber of the polarimeter is linked to the beamline by a UHV rotational feedthrough using ferrofluid sealing. It can be rotated around the axis of the light emerging from the monochromator. The chamber is supported on gimbals and installed in a rigidity bench, which can move in three dimensions. A sketch of the polarimeter is shown in Fig. 2. The system consists of an $x$-$y$ stage of exact translation (C), $I_0$ detector, polarizer assembly (P) (including the rotational stages to change the grazing incident angle $\theta_{\mathrm{P}}$ and the azimuth angle $\alpha$), moving rocker (R), sample stage (S), analyzer assembly (A) (including the rotational stage to change the grazing incident angle $\theta_{\mathrm{A}}$ and the azimuth angle $\beta$), main detector (D), data collectors and control systems. The polarimeter is equipped with HV-compatible stepper motors except for the sample stage and stage to change the azimuth angle of the polarizer. Four operational modes can be performed in the polarimeter. These modes are double-reflection, double-transmission, front-transmission-behind-reflection and front-reflection-behind-transmission (i.e., the polarizer is of the reflection type and the analyzer is of the transmission type). Fig. 3 shows schematics for the four working modes. In this device, for every mode, there are four operational patterns: energy scanning (I-$E$) method, $\theta$-$2\theta$ scanning (I-$\theta$) method, azimuth angle of the polarizer (I-$\alpha$) and azimuth angle of the analyzer scanning (I-$\beta$) method. The mica measurement was used for the azimuth angle of the analyzer scanning (I-$\beta$) method with double-reflection mode.

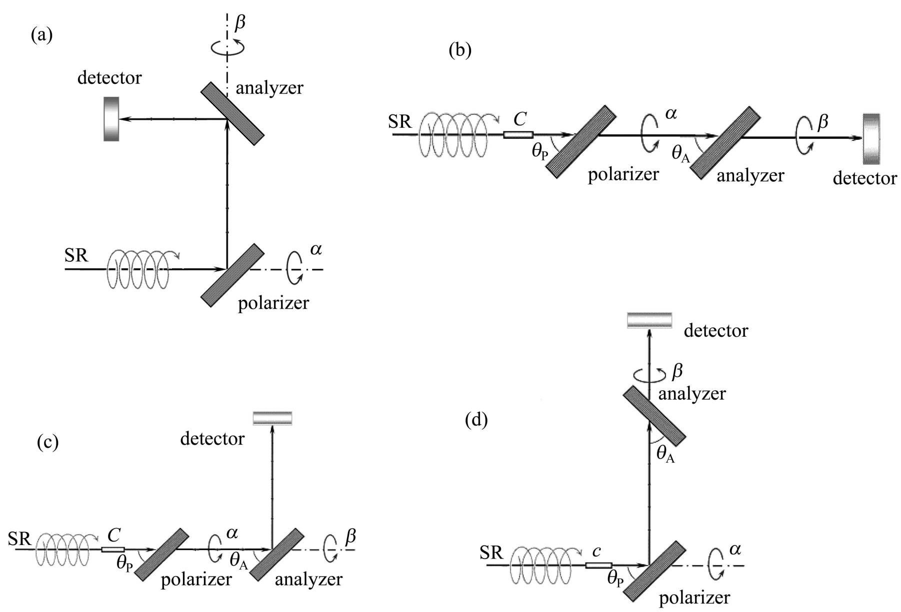


Fig. 3. Four operational modes with the polarimeter. (a) double-reflections; (b) double-transmissions; (c) front-transmission-behind-reflection and (d) front-reflection-behind-transmission.

## 4 Results and discussions

Figure 4 gives the measurement results for the reflectivity of s, p component EUV and the polarization of the mica. For a wiggler radiation, the polarization of the light source is not so good; we assumed that the s- and p-components of the EUV signals are $I_{0\_\mathrm{S}}$ and $I_{0\_\mathrm{P}}$, respectively. The total EUV signal is: $I_0 = I_{0\_\mathrm{S}} + I_{0\_\mathrm{P}}$, the contrast factor of EUV: $C_0 = I_{0\_\mathrm{S}}/I_{0\_\mathrm{P}}$ and the polarization of the light source: $P_{\mathrm{L}} = (C_0 - 1)/(C_0+1)$. The contrast factor for the synthetic mica is: $C_{\mathrm{M}}=R_{\mathrm{s}}/R_{\mathrm{p}}$ and the polarization of EUV: $P_{\mathrm{L\_M}}=(C_{\mathrm{M}} - 1)/(C_{\mathrm{M}}+1)$, here the $R_{\mathrm{s}}$, $R_{\mathrm{p}}$ and $P_{\mathrm{L\_M}}$ are different from our measured data and they are shown in Fig. 3, marked as $R_{\mathrm{s}}$', $R_{\mathrm{p}}$' and $P_{\mathrm{L\_M}}$'. They follow these equations: $R_{\mathrm{s}}'=(C_0\ R_{\mathrm{s}}+R_{\mathrm{p}})/(C_0+1)$, $R_{\mathrm{p}}'=(C_0\ R_{\mathrm{p}}+R_{\mathrm{s}})/(C_0+1)$ and $P_{\mathrm{L\_M}}'=P_{\mathrm{L\_M}}\ (C_0-1)/(C_0+1)$; all of the measured data ($R_{\mathrm{s}}$', $R_{\mathrm{p}}$' and $P_{\mathrm{L\_M}}$') are greatly affected by the polarization of the light source; in particular, the polarization of mica is much lower than its real polarization.

In this wavelength region (12–25 nm), the polarizance for 3W1B $P_{\mathrm{L}}$ is about 0.7–0.9, as discussed in previous research [14], and it is not appropriate for

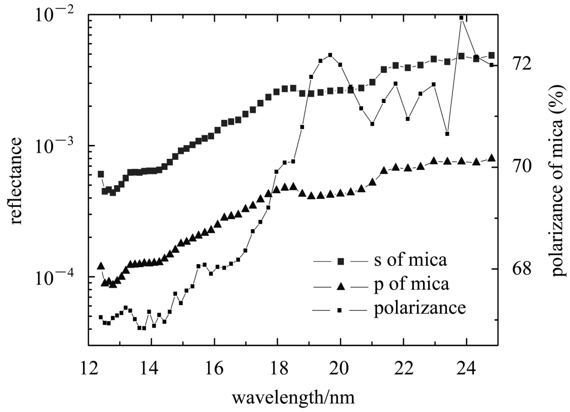


Fig. 4. The reflectivity for s-, p-component EUV and the polarizance of the synthetic mica (measured value).

MO effect measurement. Take no account of the lower reflectivity of mica as the reason we mentioned before, what mostly interests us is the polarizance of the EUV reflected by the synthetic mica crystal and how much the polarization changed. As we assumed above, the polarizance of EUV reflected by mica should be inproved from $P_L$ to $P_L$'=$(C_0C_M-1)/(C_0C_M+1)$. In the polarimeter, we measured the polarizances of EUV from the light source and reflected by synthetic mica based on a rotating-analyzer method with an analyzer of broadband Mo/Si multilayer [15] at a wavelength of 19 nm, as shown in Fig. 5. Using this rotating-analyzer method, we obtain the polarizance of the light source as about 79.8% and it increases to 96.6%, which is adaptable for MO effect research. For the narrow working region of a Mo/Si multilayer analyzer, we only measured at three wavelengths of 18, 19 and 20 nm using this method.

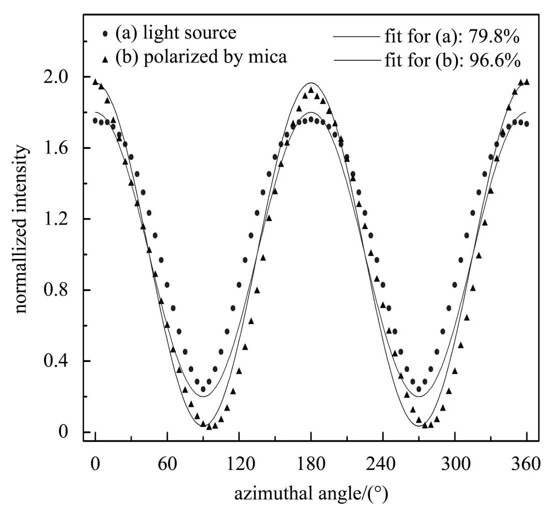


Fig. 5. The measured polarizances of the X-ray from light source and reflected by synthetic mica with the rotating-analyzer method.

Polarizances of EUV reflected by mica are 96.3%, 96.6% and 96.8% for 18, 19 and 20 nm, respectively.

For the incomprehension of the polarizance of the light source, we can't get the polarizance of the EUV reflected by synthetic mica directly in the whole wavelength range. From the reflectivity for the s- and p-components, we measured and the assumption of polarizance of light source, simulations were made to show the polarization for EUV reflected by synthetic mica. As we mentioned above, $P_L$' is greatly influenced by $P_L$: $P_L$'= $(P_L^2+P_{L\_M}')/(P_L+P_LP_{L\_M}')$. Using $P_{L\_M}$' measured before in Fig. 3, simulations of $P_L$' using four different $P_L$ (75%, 80%, 85% and 90%) are made and shown in Fig. 6. As shown in Fig. 6, no matter what the $P_L$ (between 75%–90%) is, the polarizance of EUV reflected by mica ($P_L$') is higher than 98.0% from 12 to 25 nm. The polarizance of reflected EUV ($P_L$') didn't change much with different polarizances of the light source ($P_L$), which means that a higly polarized EUV with excellent stability was obtained when reflected from the synthetic mica.

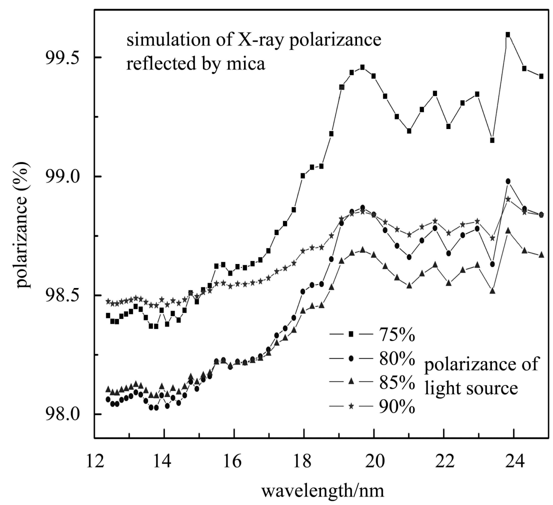


Fig. 6. Simulations of the polarizance of EUV reflected by mica ($P_L$') using four $P_L$ (75%, 80%, 85% and 90%).

The $P_L$' we measured in Fig. 4 is 96.6%, a little lower than the $P_L$' we simulated in Fig. 5; this is caused by the analyzer of Mo/Si we used in the analyzer-rotation method. Compared with the data $P_L$' in Fig. 4 and Fig. 5, the polarizance of the analyzer we obtained is about 98.0%, which agrees perfectly with the 98.5% we measured before [15].

It is clear that the synthetic mica polarizer can also be used in an extensive wavelength range higher than 25 nm because the reflectivity Rs and polarizance $P_L$ rise with the wavelength.

## 5 Conclusions

Simulations and experimental measurement are made to study the performance of synthetic mica crystal as a polarizer in the wavelength range 12–25 nm. Using the synthetic mica, the polarization of EUV increased from 80% to 96.8% at a wavelength of 19 nm, which is consistent with the performance in other wavelengths as we simulated. Though the reflectivity of synthetic mica at a pseudo-Brewster angle of 48° is not high, the polarizance of mica is appropriate for MO effect measurement and some other experiments require linear polarized EUV in 3W1B, BSRF. In some extensive wavelength region, especially higher than 25 nm, mica can also be used as a polarizer for the rising reflectivity and polarizance with the increase in wavelength.

With excellent thermal and chemical stability, the synthetic mica can be easily made and used as a polarizer in the EUV and soft X-ray region. It is good for MO effect research in the EUV and soft X-ray region, such as the Faraday effect and Kerr effect at the M absorption edge of Fe, Co and Ni, and some other materials.

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