

Space environment experiments on Mo/Si and SiC/Mg multilayers for astronomical observation

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Mo/Si and SiC/Mg period multilayer mirrors are investigated for solar He-II radiation at 30.4 nm. The optical stabilities of these multilayers are measured before and after space environment simulation tests for the purpose of potential application in space extreme ultraviolet (EUV) observations. All these multilayers are deposited by magnetron sputtering method on microcrystalline glass substrates. Then thermal cycling stability and radiation exposure experiments are performed to simulate the space environment. The testing results indicate that the Mo/Si multilayer is more stable than the SiC/Mg multilayer. The reflectivity of the SiC/Mg multilayer decreases slightly.

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In astronomical observation in the extreme ultraviolet (EUV) range, solar emission lines at wavelengths of 17.1 nm (Fe-IX), 19.5 nm (Fe-XII), 28.4 nm (Fe-XV), and 30.4 nm (He-II) can be selected for the imaging of solar corona^[1–5]. Owing to the strong absorption of most materials in the EUV region, the optical system at normal incidence requires a high reflectivity multilayer mirror. In recent years, the development of multilayer technology has enabled the construction of new instrumentation and has led to several successful missions, including a solar and heliospheric observatory/EUV imaging telescope and a transition region and coronal explorer^[1–3]. At the wavelengths longer than the Si L absorption edge near 12.4 nm, the multilayer material combinations select Si as the space layer. For example, Mo/Si was widely used in the wavelength of 13–20 nm for its high stability and high reflectivity, especially under the motivation of an EUV lithograph in the integrated circuit industry^[6]. Mo/Si can provide more than 70% normal incident reflectivity near at 13-nm wavelength but only 23% at 30.4 nm. Therefore, a new material combination is required to be developed for a 30.4-nm wavelength. The theoretical reflectivity of the SiC/Mg multilayer is as high as 56% at 30.4 nm as the space material of Mg has its absorption edge at 25.2 nm. However, Mg is an active element. The stability of the Mg-based multilayer was investigated^[7–9]. In this letter, the stabilities of these multilayers are investigated before and after space environment simulation tests (thermal cycling stability test and radiation exposure) for the purpose of potential application in space EUV observation. The multilayer

structure is measured by an X-ray diffractometer (XRD), and reflectivity is measured by a reflectometer at the national synchrotron radiation laboratory (NSRL) in Hefei, China.

At the wavelength of 30.4 nm, the maximization of peak reflectivity using a conventional periodic multilayer method was used to design SiC/Mg and Mo/Si period multilayer mirrors at an incident angle of 10°. The design parameters are listed in Table 1.

Then all these multilayers were prepared on super-smooth polished microcrystalline glass substrates by an ultrahigh vacuum direct current magnetron sputtering system (JGP560C, Sky Ltd., China) with four 100 mm diameter sputtering sources^[10]. After deposition, all these multilayer mirrors were characterized by an XRD (D1 system, Bede Ltd., UK) working at a Cu K α line (0.154 nm), and the reflectivities were measured at NSRL. To perform the thermal cycling stability test and the radiation exposure experiment, six pieces of samples were prepared for each multilayer material combinations listed in Table 1. Three samples were used for the thermal cycling test, and three samples were used for the radiation exposure experiment. That is, for each experimental test, these samples were repeated.

After preparation, the thermal cycling stability and radiation exposure experiments were performed to simulate space environment. Before and after space environment simulation tests, these multilayer mirrors were characterized by XRD and synchrotron radiation for comparison.

The thermal cycling tests were performed in a vacuum at 1.3×10^{-3} Pa. The samples were kept at a low tem-

Table 1. Design of SiC/Mg and Mo/Si Period Multilayers at an Incident Angle of 10°

Multilayer	Bilayer Number	Period (nm)	Scattering Layer (nm)	Space Layer (nm)	Calculated Reflectivity (%)
SiC/Mg	30	15.83	4.91	10.92	55.93
Mo/Si	10	16.63	4.32	12.31	23.47

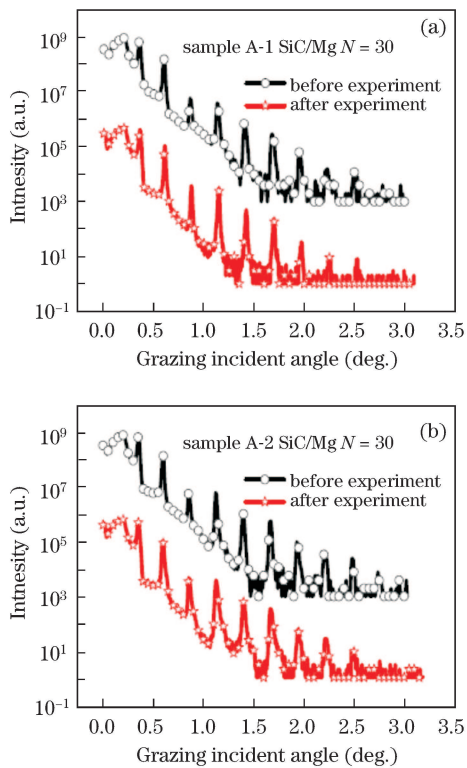


Fig. 1. XRD measured results of the SiC/Mg multilayer before and after (a) thermal cycling stability test and (b) radiation exposure experiment.

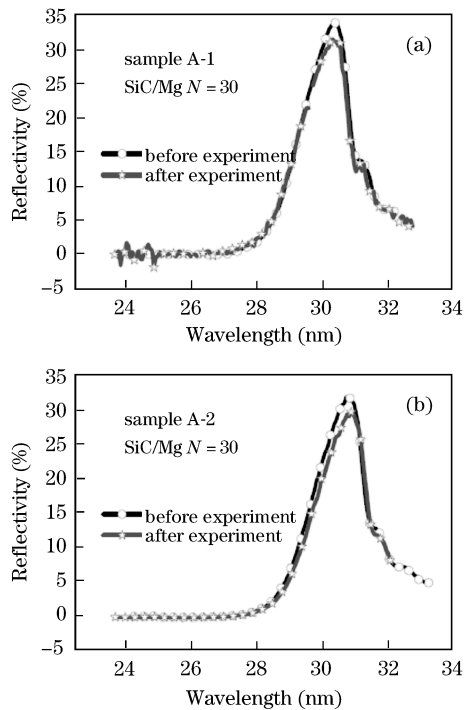


Fig. 2. Reflectivity measurement results of the SiC/Mg multilayer before and after (a) thermal cycling stability test and (b) radiation exposure experiment.

perature of $-45\text{ }^{\circ}\text{C}$ for 24 h and at a high temperature of $145\text{ }^{\circ}\text{C}$ for 12 h. The thermal cycle test was repeated three times. The radiation exposure experiment was performed using ^{60}Co as the gamma radiation source, and

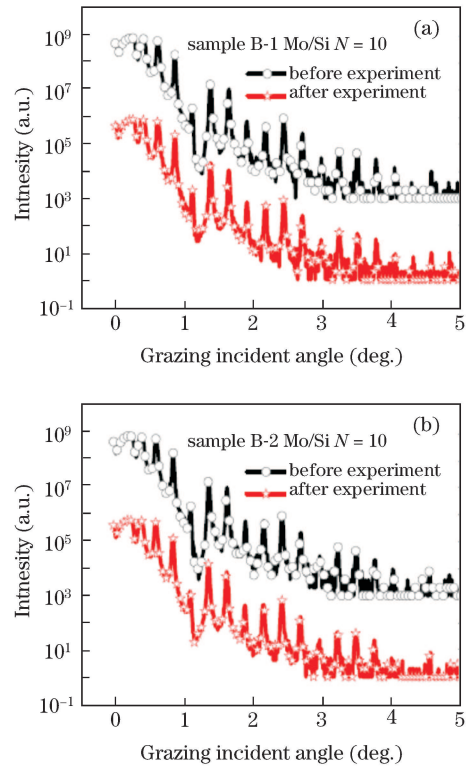


Fig. 3. XRD measured results of the Mo/Si multilayer before and after (a) thermal cycling stability test and (b) radiation exposure experiment.

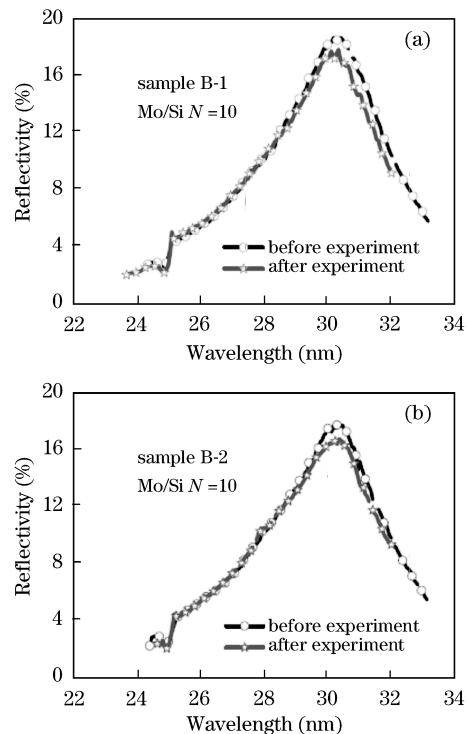


Fig. 4. Reflectivity measurement results of the Mo/Si multilayer before and after (a) thermal cycling stability test and (b) radiation exposure experiment.

the total radiation dosage was 100 krad (Si). Before and after the thermal cycling stability test and the radiation exposure experiment, each multilayer mirror was char

Table 2. Reflectivities of SiC/Mg and Mo/Si Multilayer Mirrors before and after Simulating Space Environment

Multilayer	Thermal Cycling		Radiation Exposure	
	Stability		Experiments	
	Before (%)	After (%)	Before (%)	After (%)
SiC/Mg	34.0	31.0	31.4	29.4
Mo/Si	18.6	17.8	17.8	16.8

acterized by XRD and synchrotron radiation, and then the multilayers were compared. The measured results are shown in Figs. 1–4. From the XRD measurement, no significant change is observed. The reflectivities are all listed in Table 2. It can be seen that the reflectivity of SiC/Mg decreases by 3%, and that of Mo/Si decreases by only 1%.

In conclusion, for the purpose of EUV imaging solar corona by selecting a He-II emission line at a wavelength of 30.4 nm, SiC/Mg and Mo/Si material combinations are introduced in IPOE. The optical stabilities of these multilayers are investigated before and after space environment simulation tests. The thermal cycling stability test and radiation exposure experiment results indicate that all the multilayers can bear the space simulation tests. The Mo/Si multilayer is more stable than the SiC/Mg multilayer. However, the SiC/Mg multilayer provides a much higher reflectivity more than 30%, about two times that of Mo/Si. Although the reflectivity decreases slightly (3%) in the thermal cycling stability test and the radiation exposure experiment, the SiC/Mg multilayer is promising in a solar observation at 30.4 nm.

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