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Research Note

Study for dual-function EUV multilayer mirror

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Abstract

Studying the distribution of He^+ in Earth's plasmasphere by detecting its resonantly scattered emission at 304 Å will record the structure and dynamics of the cold plasma in Earth's plasmasphere on a global scale. EUV imaging systems usually utilizes near-normal incidence optics including multilayer mirror and filter. In this paper, the space condition of the Earth's plasmasphere to confirm the expected performance of mirror were analyzed. In order to achieve higher response at 304 Å and reduce 584 Å radiation for the optical system, a new multilayer coating of Mo/Si with UO_2 was developed. Based on optical constants of Mo, Si and UO_2, we used a simplest method to compute the reflectance of this new multilayer mirror range from 100 to 584 Å. The results show the desirable thickness of UO_2 is 17 Å, and the multilayer mirror has a high reflectance of 26.10% at 304 Å and a low reflectance of 0.52% at 584 Å.

Keywords: EUV; Multilayer mirror; UO_2

1. Introduction

Helium ions are the second major component in the plasmasphere (almost 10% of the total amount [1]) and resonantly scatter the solar He^+ EUV emission at 304 Å. Hence detecting this emission spectrum will lead to its global image.

The He^+ emission was first observed in the late 1960s and early 1970s by EUV photometers on several rockets [2–4], on the STP 72-1 satellite, Black Brant VC satellite and on the Apollo-Soyue mission. In 1998, Planet-B in a parking orbit around the Earth first imaged the plasmasphere from the outside of it [5]. In 2000, IMAGE was the first mission to observe full-plasmasphere images from outside the plasmasphere [6]. Fig. 1 shows the EUV photograph imaged by IMAGE in 2000.

However, there are other strong emissions in addition to the signal at 304 Å, such as Lyman-αH (1216 Å) from the geocorona and interplanetary medium and He (584 Å) from the ionosphere, and the two lines are much brighter than the 304 Å line. Other emissions with wavelength between 584 and 1216 may also be present, but their intensities should be relatively smaller [7]. The 1216 Å emission is blocked by an Al filter. Al is relatively transparent to 584 Å line. There is no acceptable filter for blocking 584 Å. So the design of a multilayer mirror for this task must have two optical functions, i.e., it must have reflectance at 304 Å but low reflectance at 584 Å.

In this paper, we developed a new multilayer coating of Mo/Si multilayer with single layer UO_2 satisfying the above two functions. Furthermore, the optimization thickness of UO_2 was studied.

2. Multilayer mirror designing

Multilayer mirror is an interference device and its operation is analogous in some ways to Bragg relation. The refraction-corrected Bragg formula for a multilayer is given by

$$m\lambda = 2d\sin\theta\left[1 - \frac{2(d_t\delta_t + d_l\delta_l)}{\sin^2\theta}\right], \tag{1}$$

where m is the order of reflection, λ the radiation wavelength, d the constant bilayer optical length and θ is the angle of incidence from the surface, d_t, and d_l are the

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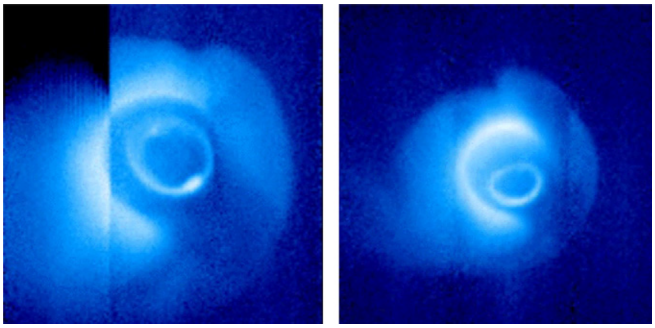

Fig. 1. The EUV photograph imaging by IMAGE in 2000.

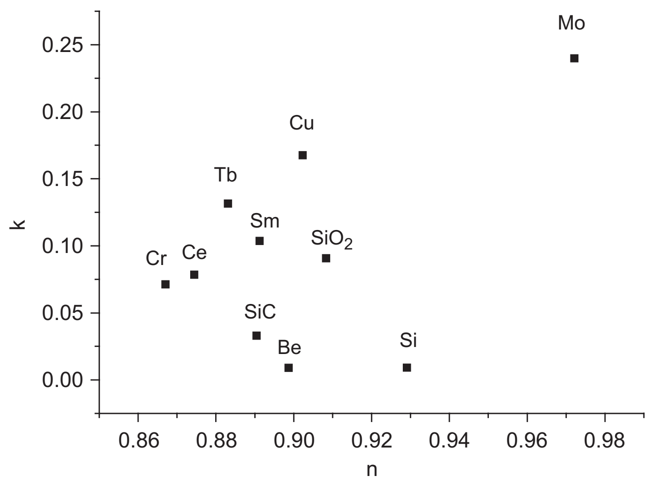

Fig. 2. Complex indices of the materials at the wavelength 304 Å.

thicknesses of top material and low material, respectively, δ_t, and δ_l are the corresponding complex refraction indices:

$$n_t = 1 - \delta_t - i\beta_t \tag{2}$$

and

$$n_t = 1 - \delta_l - i\beta_l. \tag{3}$$

As seen from the above equation, we know that the multilayer mirror must be designed to operate at a particular wavelength and angle of incidence, and it is important to choose materials and decide layer thickness distribution. The optical criteria for material selection are that the two materials must simultaneously have the highest optical contrast and the lowest absorption possible. The optical constants of some materials at the wavelength of 304 Å are plotted in Fig. 2 obtained from the Center of X-ray optics worldwide web server at Lawrence Berkeley National Laboratory of USA [8]. From Fig. 2, it can be seen that the reflectance index of Si is low and the optical contrast between Mo and Si is highest, so Mo and Si are accepted. Another advantage is that it is very stable under vacuum and atmosphere and has high reflectance in the EUV region.

We kept the bilayer thickness constant and verified Γ parameter ($\Gamma = d_{Mo}/d_{Mo} + d_{Si}$) in order to choose the optimization layer thickness distribution. The reflectance

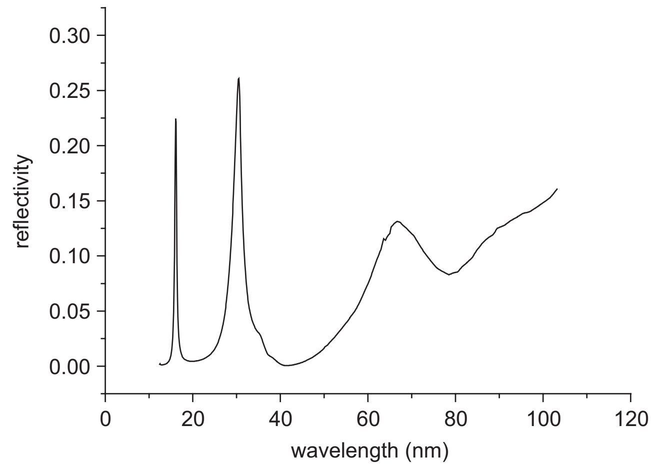

Fig. 3. Reflectance of a Mo/Si multilayer mirror (41 Å/124 Å, 40 layers) at normal incidence.

of Mo/Si multilayer mirror was computed using optical constants [8,9], which was plotted in Fig. 3. It shows it has high reflectance at 304 Å of 26.06%, while also has reflectance of 6.05% at 584 Å. Nevertheless, the design requirements called for the mirror that has high reflectance at 304 Å but low reflectance at 584 Å. To reflect well at 304 Å and poorly at 584 Å, it requires an additional thin film which reflects well at 304 Å and must act as an antireflection layer at 584 Å.

3. Dual function multilayer mirror design

Multilayer mirror having high reflectance at 304 Å and low reflectance at 584 Å must be rare because most materials have much higher single layer reflectance at 584 Å than at 304 Å. We studied IMAGE and found that UO_2 was expected and it had been proved responsible for the low reflectance at 584 Å [10]. The next consideration is to optimize the thickness of UO_2 in order that the multilayer fulfills the two functions.

The reflectance computations were based on optical constants and optical constants for UO_2 obtained theoretically from the literature [8,11,12]. But as far as we are aware, no data exist on the exact optical properties of UO_2 range above 584 Å. Hence, the wavelength range for computing the reflectance of Mo/Si multilayer mirror with UO_2 was just from 100 to 584 Å, just as is the following parts.

First, it was necessary to choose a suitable optimization method to obtain the best thickness. Meanwhile, the way should also be simplest and computate easily. When the top layer was coated with some certain thickness of UO_2, the only thing to do was to change the air medium into this material and verify the optical constant subsequently. There was no need to optimize the multilayer thickness again and we only need to adjust the thickness of the outermost UO_2 to make this thin single layer thickness optimal.

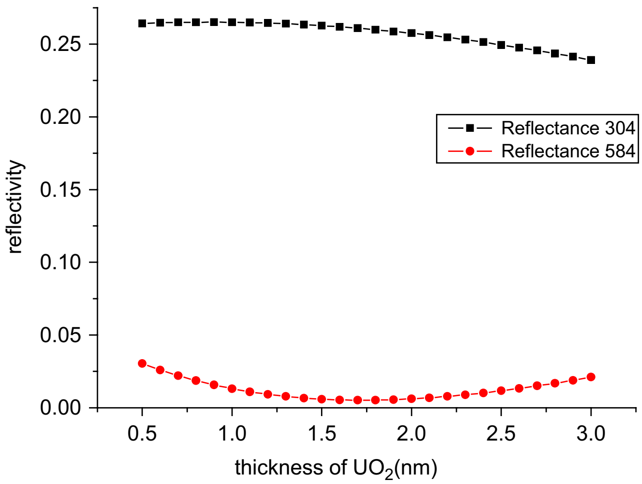

Fig. 4. Reflectivity of Mo/Si multilayer mirror with thickness of UO_2 at 304 Å and at 584 Å.

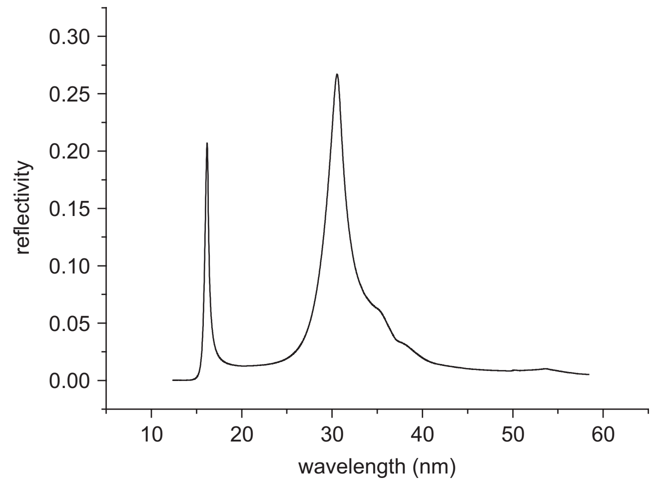

Fig. 6. Reflectance of a Mo/Si multilayer mirror (41 Å/124 Å, 40 layers) with 17 Å UO_2 layer at normal incidence.

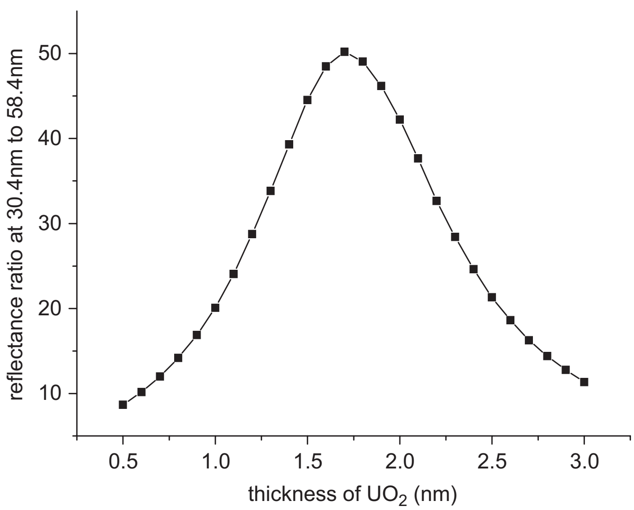

Fig. 5. Ratio of the reflectivity at 304 Å to at 584 Å with the different thicknesses of UO_2.

We computed the reflectivity of Mo/Si multilayer coupled with UO_2 varied with thickness of UO_2 at 304 Å and at 584 Å see Fig. 4. It is obvious that when thickness of UO_2 increases reflectivity of 304 Å radiation reduces steadily. However, it does not do so for 584 Å radiation. When the thickness of UO_2 is 17 Å, the reflectivity of multilayer at 584 Å is lowest. Fig. 5 indicates the ratio of the reflectivity at 304 Å to that at 584 Å with the different thicknesses of UO_2, and the peak is at 17 Å. So the optimization thickness of UO_2 is 17 Å, and Fig. 6 indicates the reflectance of Mo/Si multilayer mirror with 17 Å UO_2. The reflectance is 26.10% at 304 Å and 0.52% at 584 Å.

However, in EUV region, interfacial and surface roughness can severely influence the performance of multilayer mirror at normal incidence. Thus, the roughness must be taken into account. Modeling the effects is usually to use the standard analysis based on the Debye theory. Assuming that the mean position of a layer boundary is not altered by the roughness, the amplitude of the reflectance of multilayer mirror can be given by

$$R = R_0 D(\sigma), \tag{4}$$

where R_0 is the ideal smooth surface reflectance, $D(\sigma)$ is Debye–Waller factor given by

$$D(\sigma) = \exp\left[-\frac{1}{2}\left(\frac{4\pi\sigma \sin\,\theta}{\lambda}\right)^2\right], \tag{5}$$

where θ is the grazing incidence angle, λ the incidence wavelength, σ the rms surface roughness. At normal incidence, the ratio σ/λ must be as small as possible, that is, σ is at least smaller than 10 Å, because EUV wavelength $\lambda = 10$–100 Å. Furthermore, the surface roughness is decided by substrate roughness. Therefore, the reflectance of multilayer mirrors fabricated under the same conditions are mainly affected by the substrate roughness. Moreover, the increasing period number of multilayer can improve its interfacial quality. So the substrate roughness must be better than 10 Å. In this way, the reflectance of multilayer mirror will be reduced only a little at 304 Å and will not be affected very much.

4. Conclusion

We have developed a new EUV multilayer mirror of Mo/Si multilayer mirror with UO_2, and it satisfied two functions. It has high reflectance at 304 Å and low reflectance at 584 Å. Computing the reflectance varied with thickness of UO_2 to achieve optimization thickness of UO_2. we can see that the best thickness of UO_2 is 17 Å and the reflectance of it is 26.10% at 304 Å and 0.52% at 584 Å. In order to achieve high reflectance of multilayer mirror, the substrate roughness has to be better than 10 Å.

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