Experiment and Application of Soft X-ray Grazing Incidence Optical Scattering Phenomena

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ABSTRACT

For short wavelength imaging systems，surface scattering effects is one of important factors degrading imaging performance. Study of non-intuitive surface scatter effects resulting from practical optical fabrication tolerances is a necessary work for optical performance evaluation of high resolution short wavelength imaging systems. In this paper, Soft X-ray optical scattering distribution is measured by a soft X-ray reflectometer installed by my lab, for different sample mirrors、wavelength and grazing angle. Then aim at space solar telescope, combining these scattered light distributions, and surface scattering numerical model of grazing incidence imaging system, PSF and encircled energy of optical system of space solar telescope are computed. We can conclude that surface scattering severely degrade imaging performance of grazing incidence systems through analysis and computation.

Keywords: Soft X-ray, Grazing Incidence, Optical Scattering Phenomena, Experiment

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1. INTRODUCTION

With the development of the space times, the space technology is becoming more and more dependent on the space technology. The solar activity directly affects and restricts the change of the near earth space environment [1, 2]. The characteristics of soft X-ray band are more obvious when the solar bursts occur. Therefore, it is of great significance to carry out the soft X-ray observation to predict the solar activity and space weather. In the observation of the solar spectrum, the soft X-ray band imaging observation has a unique advantage in the development of space weather forecast. Study on the soft X-ray imaging system, not only can help the change of human monitoring of the space environment, ensure the production safety of life, but also can help people further understand the mysteries of the universe, the universe provides important data. At present, the research of grazing incidence space soft X-ray imaging telescope in our country is still in the initial stage and has not been put into operation [3, 4]. Based on the importance of space environment monitoring, it is urgent to research and develop the space soft X-ray telescope. The grazing incidence optical system has the advantages of wide range of working wavelength, and so on. In the soft X-ray band, the commonly used grazing incidence telescope is Wolter-I telescope. For this optical system, effective light area and surface scattering are two important factors that affect the imaging quality [5-8]. This paper focuses on the space of soft X-ray grazing incidence optical system, from the aspects of smooth surface scattering, soft X-ray reflectivity we developed the application respectively for mirrors with different samples, experiments were carried out to study the surface scattering of optical radiation soft X-ray band in different bands of grazing and grazing angle under the condition of. After data processing, respectively, analyzed the influence of grazing angle, wavelength and roughness factors of grazing incidence soft X-ray surface scattering from the experimental point of view; On the other hand, start from the application, space solar telescope optical system soft X-ray image quality evaluation, discuss the influence of optical surface scattering on the quality of soft X-ray grazing incidence imaging optical system [9].

2. SOFT X-RAY GRAZING INCIDENCE OPTICAL SCATTERING EXPERIMENTATION

On the surface scattering experiment, influence of surface scattering upon reflector is incarnated on the effective area. Based on the existing conditions of LAB, data of optical scattered distribution are obtained by soft X-ray reflectometer. The soft X-ray reflectometer consists of a laser-produced-plasma (LPP) light source with gas-jet target, a monochromator, a high vacuum sample chamber, a vacuum pumping system and an electronics unit shown in Fig.1.
Laser plasma light source produced by the soft X-ray continuous spectrum after grazing incidence of constant Angle monochromator, select the required working wavelength of monochromatic light, and then enter indoor sample;

Monochromatic soft X-ray after mirror reflection under test by channel electron multiplier detection, probe detection results by general computer output by data acquisition system, realize the surface scattering measurement. The following is the specific content of grazing incidence optical surface scattering experiment respectively discussed, first of all samples selected from the beginning.
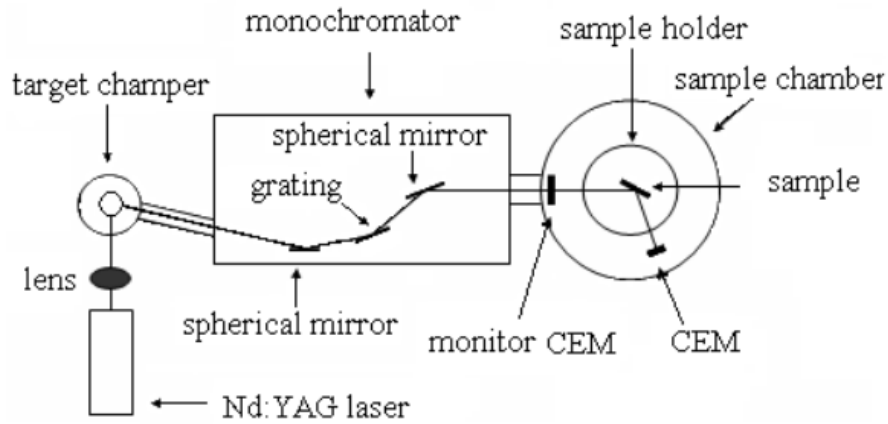

Fig.1: Schematic diagram of the soft X-ray reflectometer

2.1 Sample

In this experiment, according to the optical materials and surface morphology, choose two different samples of mirror. Two pieces of samples are flat mirror, one is a piece of microcrystalline glass material, and another piece of sample is silicon. Microcrystalline glass with low thermal expansion coefficient, good thermal stability, dimension stability and high mechanical strength and become a large optical instrument mirror of high quality materials; Silicon is a kind of commonly used optical lens materials. Before the surface scattering experiment, we first adopt WYKO surface contourgraph respectively on the surface roughness of the two pieces of test samples determined, the results of the determination of as shown in figure.2, which (a) of silicon mirror under test samples, (b) as microcrystalline glass mirror under test samples. As can be seen from the two diagrams, silicon overall surface roughness RMS values of the sample under test is 1.3 nm, and microcrystalline glass overall roughness RMS values of the sample under test is 1.5 nm.
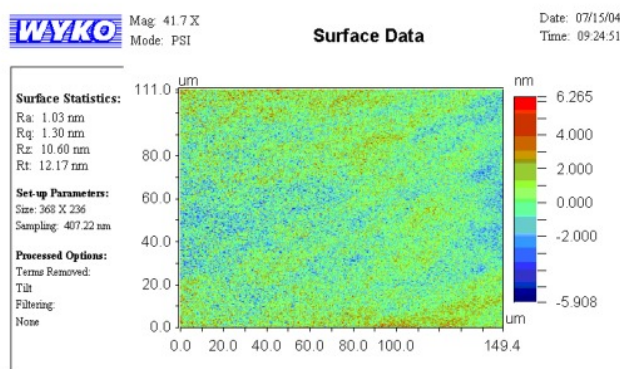

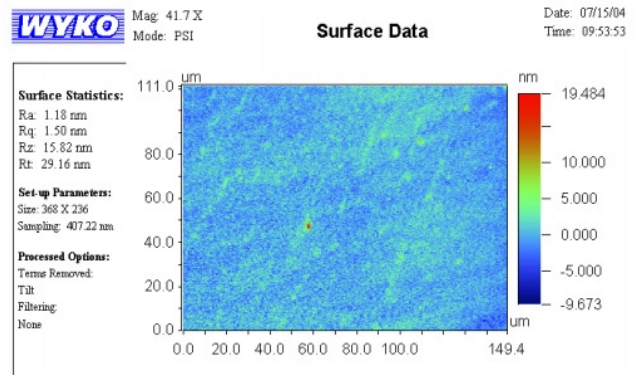Fig.2(a): Surface data of Si sample by WYKO   Fig.2(b): Surface data of glass-ceramics sample by WYKO

2.2 Different factors effects on surface scattering

In experiment, the first measured surface scattering Angle distribution of different wavelengths, namely for the same sample under test, on the basis of the grazing angle, the surface of different wavelength of incident light scattering experiment; Change the grazing Angle, then continue to measure the surface scattering distribution in the different

wavelengths; When several after the grazing Angle measured, turn off the system, change different sample under test, the vacuum, high pressure until at least 1000v, repeat the previous experimental process of the sample under test. By using these scattered light distributions of super-smooth surfaces measured by the soft X-ray reflectometer, for different sample mirrors、 wavelength and grazing angle. By dealing with experimental data, different factors effects on surface scattering, such as glancing angle、wavelength and roughness is computed and analyzed.

2.2.1 Wavelength

For soft X-Ray grazing incidence optical surface scatter do not satisfied approximation of smooth surface, so there is no directly proportion between wavelength and surface scattering, and these relation will be analyzed by experimentation. Based on compute process of surface roughness, we get effective scattering distribution and incidence distribution of glass-ceramics sample while wavelength is 8nm、 9nm、 10nm、 10nm and grazing incidence angle is 1.5°, shown in Fig. 3(a), and effective scattering distribution and incidence distribution of Si sample while wavelength is 13nm、 14nm 、15nm、 16nm and grazing incidence angle is 1.5°, shown in Fig. 3(b). From Fig.3, same surface roughness, same grazing angle, along with decrease of wavelength, optical surface scatter is more serious, and reduce performance of optics, and then we can see that for short wavelength optical system, optical surface scattering research is very important.
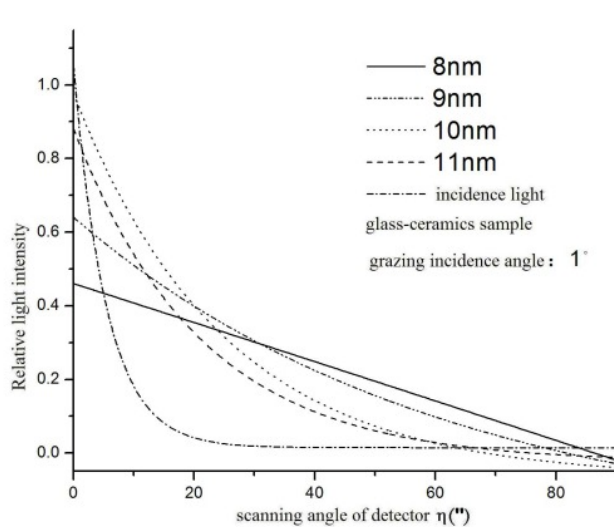

Fig.3(a): $\phi=1°$ effective scattering distribution of glass-ceramics sample with different wavelength
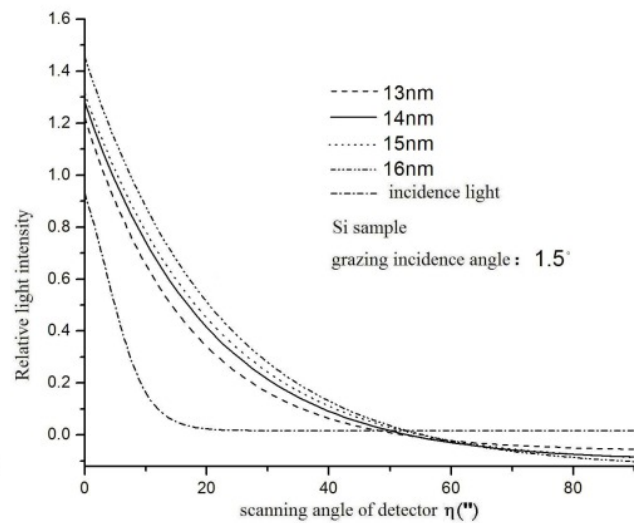
Fig.3(b): $\phi=1.5°$ effective scattering distribution of Si sample with different

2.2.2 Surface roughness

Effective scattering distribution and incidence distribution of Si sample and glass-ceramics sample is shown in Fig. 4(a) while wavelength is 8nm and grazing incidence angle is 1°, where abscissa is scanning angle of detector η (difference of scattering angle θ and incidence angle θ_0). Figure 3 (b) is effective scattering distribution and incidence distribution of two pieces of samples while wavelength is 11 nm, grazing Angle is 1.5 °.

From Fig.4, we can see the silicon sample scattering degree is not as serious as the scattering degree of microcrystalline glass sample, and from the previous figure 2, we know surface roughness of silicon samples is smaller than the microcrystalline glass samples. Therefore, we can come to a conclusion that is in the soft X-ray band, with the increase of surface roughness, surface of grazing incidence optical scattering is more and more serious. In that case, we fully proved that increasing the surface roughness through the experiment can aggravate the degree of grazing incidence optical surface scattering, the serious influence the image quality of grazing incidence optical imaging system.
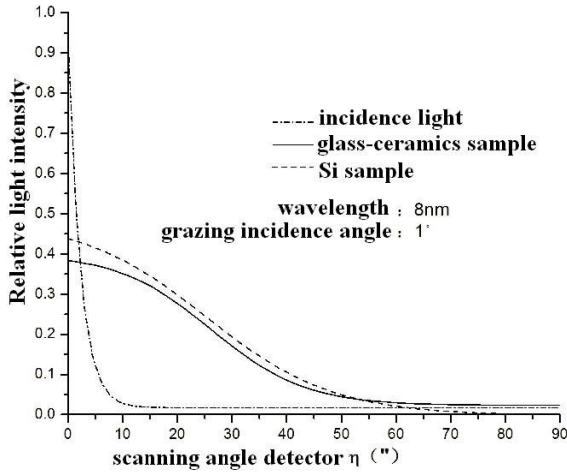
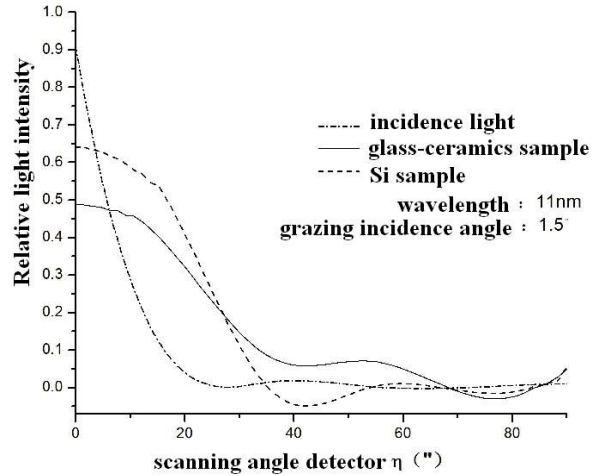Fig.4(a): $\lambda = 8nm$、 $\phi = 1°$ effective scattering distribution and incidence distribution with different roughness

Fig.4(b): $\lambda = 11nm$、 $\phi = 1.5°$ effective scattering distribution and incidence distribution with different roughness

2.2.3 Grazing angle

Grazing angle is complementary angle of incidence angle, so grazing angle affection is same with incidence angle affection discussed. Grazing angle is in the phase function of pupil function, has influence on the scattering distribution. Effective scattering distribution and incidence distribution of glass-ceramics sample while wavelength is 9nm and grazing incidence angle is1°、 1.5°、 2°, is shown in Fig.5(a), and effective scattering distribution and incidence distribution of Si sample while wavelength is 11nm and grazing incidence angle is1°、 1.5°、 2°, is shown in Fig.5(b). From Fig.5, same surface roughness, same wavelength, along with increase of grazing angle, optical surface scatter is more serious, and reduce performance of optics, and then we can improved optical performance through decrease grazing angle.
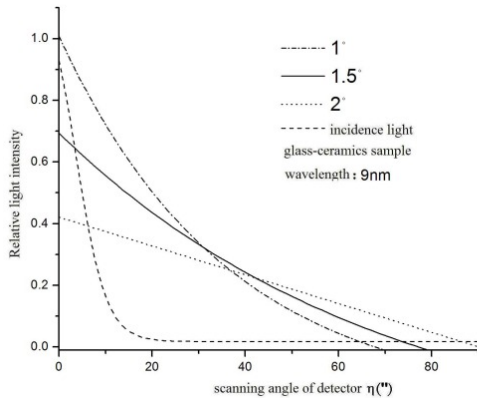

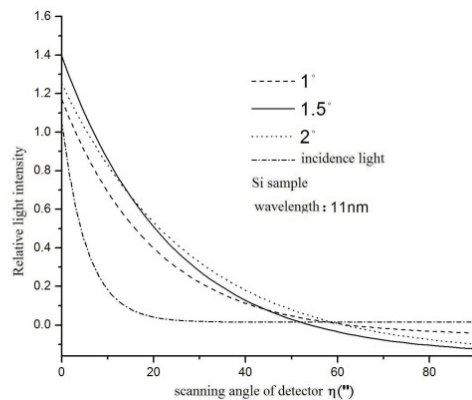Fig.5(a): $\lambda = 9nm$ effective scattering distribution of glass-ceramics sample with different grazing angle

Fig.5(b): $\lambda = 11nm$ effective scattering distribution of Si sample with different grazing angle

Above, from the Angle of the experiment, we have analyzed respectively the influence of grazing Angle, wavelength and surface roughness on soft X-ray grazing incidence scattering, we will discuss below application of Soft X-ray Grazing Incidence Optical Scattering Phenomena.

3. APPLICATION: EFFECTS OF SURFACE SCATTERING TO IMAGING PERFORMANCE OF SPACE SOLAR TELESCOPE

Aperture diffraction、geometric aberrations、surface scatter and other errors (setting errors、environmental errors) are several influencing factors on imaging performance of optical system. Especially for short wavelength imaging systems, Surface scattering effects is one of important factors degrading imaging performance. Aimed at Wolter-I grazing incidence optical system of space solar telescope, by combining those scattered light distributions of super-smooth surfaces measured, and surface scattering mathematical model of space solar telescope grazing incidence imaging system, effects of surface scattering to imaging performance of space solar telescope will be evaluated then, and applying of surface scattering in imaging evaluation of soft X-ray grazing incidence optical system will be discussed.

Distribution of effective scattering is shown in Fig.5 while wavelength is 16nm and grazing incidence angle is 1.5°, where abscissa is scanning angle of detector. Scattering light distribution shown in above Fig.6(a) is convolution of incidence light distribution and sample scatter PSF

$$I = S * I_{incident\ light}$$

Based on effective scattering distribution and incidence distribution of glass-ceramics sample while wavelength $\lambda =$ 16nm、$\phi = 1.5°$ (shown in Fig. 6(a)), through deconvolution, we can obtain angle spread function and encircled energy of optical system of space solar telescope are obtained, shown in Fig.6(b), 6 (c), 6 (d). from Fig. 6 (c), Radius of scatter facula covered 63% energy is $19''$ through computing. If now image core is calculated, except surface scatter, effects of aperture diffraction geometric aberrations and other errors are calculated also, we can get encircled energy of space solar telescope, shown in Fig.6(d), and radius of light facula covered 63% energy is $22''$.
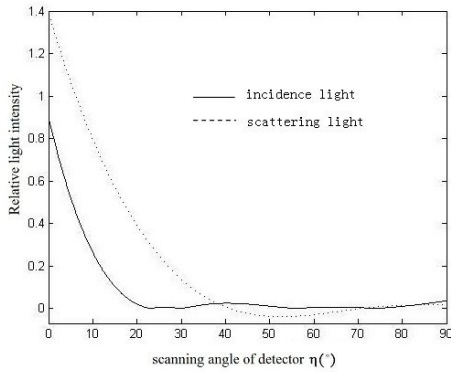

Fig.6(a): $\lambda =16nm,$ $\phi=1.5°$ effective scattering distribution of glass-ceramics sample distribution
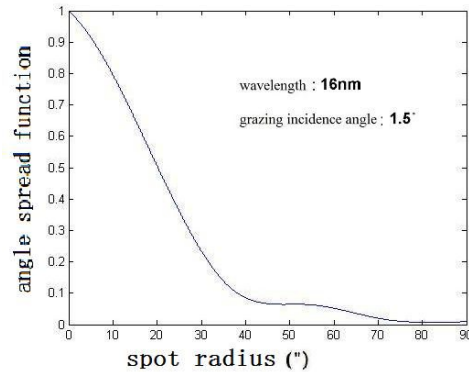

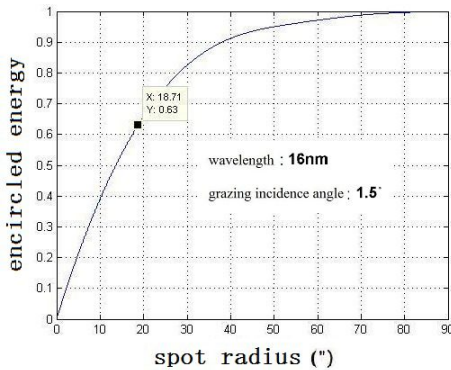Fig.6(b): $\lambda =16nm,$ $\phi=1.5°$ angle spread function of space solar telescope

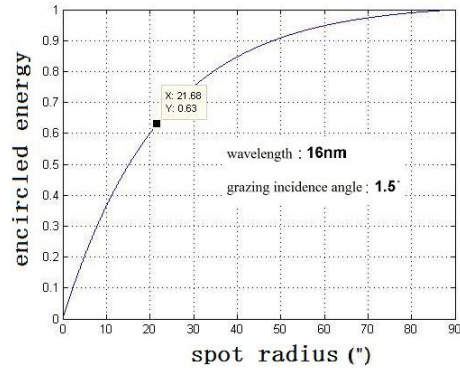Fig.6(c): dimension of image core is zero,encircled energy Of space solar telescope

Fig.6(d): $\lambda =16nm,$ $\phi=1.5°$ encircled energy Of space solar telescope

4. CONCLUSION

Based on the analysis of experimental results the parameters such as surface roughness, wavelength and grazing Angle influence on grazing incidence surface scattering, research has shown that with the increase of surface roughness, grazing Angle increase and the decrease of the wavelength, grazing incidence optical scattering phenomenon is more and more serious. And aimed at Wolter- I grazing incidence optical system of space solar telescope, by combining those scattered light distributions of super-smooth surfaces measured, and surface scattering mathematical model of space solar telescope grazing incidence imaging system, we evaluated effects of surface scattering to imaging performance of space solar telescope. From point spread function and encircled energy of solar telescope optical system, we got a conclusion that Surface scattering is one of the main factors influencing the grazing incidence telescope image quality.

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