Surface Roughness Measurements of X-Ray Mirrors

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1. Introduction

Many experimental methods have been applied to the characterization of surface finishes of hard X-ray mirrors. One of the most useful methods is the measurement of X-ray reflections and scatterings from the mirror surface, since the wavelength and experimental arrangement are similar to those in practical use. The power spectral density (PSD) of the surface wavings of the mirror is derived from the angle resolved scattering (ARS) curve of X-rays, which is informative about the mirror surface roughness[1]. On the other hand, the measurements with an optical surface profiler and a scanning tunneling microscopy (STM) have been standardized for the surface characterization of X-ray mirrors in industrial facilities and laboratories. The reliability and characteristics of these methods, however, have not been clearly understood. Thus, we planed to investigate the performance of the three kinds of methods, i.e., X-ray, optical profiler and STM measurements.

2. Methods

2.1 Experimental

Two sample mirrors were prepared, which were 50 x 50 mm^2 in surface area and 10 mm in thickness. Their materials were sintered SiC substrate with CVD-SiC coating. They were polished to have different surface roughness, which was measured with an optical profiler (Zygo, Heterodyne profiler-5500). They were coated with 100 Å Cr and 1000 Å Pt by vacuum evaporation. The substrates were fabricated by Toshiba Ceramic Co. Ltd., and the polish and evaporation were performed by Canon Co. Ltd.. After the coating, the mirror surface were characterized by the X-ray, optical profiler and STM (Digital Instrument, Nonoscope II).

In the X-ray measurements, the CuKα from a rotating anode generator (Rigaku, RU-200BE) was used. The beams incident on the sample mirror were collimated by a pair of 10 μm line slits with a distance of 147 mm, corresponding to an angular divergence of about 28 arcsec. The sample mirror was mounted on a θ-2θ goniometer placed at 466 mm downstream from the source. The exit line slit with an opening of 10 μm was placed at 80 mm downstream from the mirror. Thus, the beam width was geometrically estimated to be 16 μm at the mirror and 27 μm at the exit slit. The X-ray intensity was detected with a scintillation counter. It generally took a few hours to record an ARS curve.

2.2 Definition of surface roughness

We simply consider that the one-dimensional mirror surface profile is the sum of surface wavings with various wavelengths, l's. When the height at x position on the mirror surface is represented $Z(x)$, the PSD of surface wavings, $w(p)$, is defined by

$$w(p) = (1/2L)\left| \int Z(x)\exp(ipx)\, dx \right|^2,$$

where p is the surface wave number given by

$$p = 2\pi/l.$$

For the X-ray scattering, the wavelength of surface waving satisfying the diffraction condition is, then

$$p = 2\pi (\cos\theta_s - \cos\theta_i) / \lambda,$$

where λ, θ_i and θ_s are the X-ray wavelength, the incidence and scattering angles from the mirror surface, respectively. The root mean square (RMS) of surface roughness s is defined in the term of the surface height function, $Z(x)$, and can be written by the integral of the PSD as follows

$$\sigma^2 = (1/2L) \int Z(x)^2 dx = (1/2\pi) \int w(p)\, dp.$$

3. Results and Discussion

The optical profiler and STM were used to measure the surface height function. The optical profiler data showed that the mirrors had the RMS surface roughness of about 9 and 18 Å for the samples named A and B, respectively. On the other hand, the STM data showed the RMS roughness of about 37 Å for both mirrors. The difference between the two measurements was thought to come from the difference in the size of the observation area.

We measured the ARS curves and derived the PSD using the conventional formula proposed by Church et al.[2]. Figure 1(a) shows the PSD as a function of the surface wave number, p, at a glancing angle of 0.35°. The RMS surface roughness calculated from the PSD was about 6 and 10 Å for the samples A and B, respectively, which are summarized in Table I together with those from the optical profiler and the STM. The magnitudes of the RMS roughness by X-rays is similar to those measured by the optical

profiler. Figure 1(b) and (c) also show the PSD calculated by the Fourie transformation of the surface height functions measured by the optical profiler and by the STM, respectively. In the X-ray and optical profiler measurements, the PSD for the sample B has larger value than that for the sample A in the whole region. On the contrary, the STM data does not show a significant difference between the two mirrors.

In the X-ray measurements, the minimum and maximum values of the surface wave number of PSD were experimentally determined by the minimum angle where the scattering component can be separated from the specular reflection in the ARS curve and by the maximum scattering angle, respectively. With the grazing mirror reflection in the hard X-ray region, the range of surface wave number was known to be from 10^{-2} to 1 μm^{-1}.

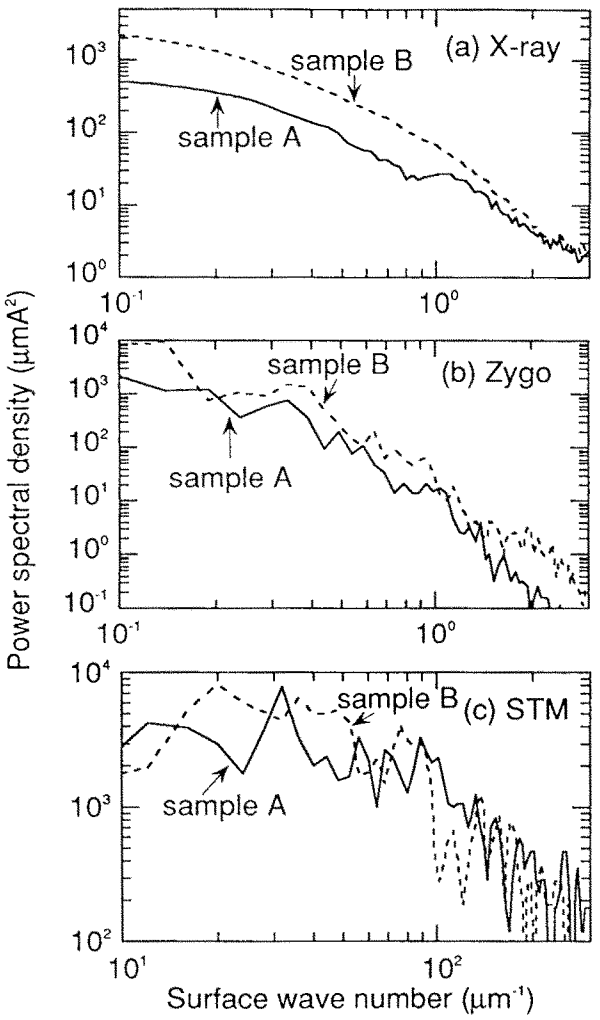

Fig.1 PSD obtained from (a) X-ray, (b) optical profiler, and (c) STM measurements.

Table I. Comparison of RMS surface roughness measured by X-ray, optical profiler and STM.

Sample	X-ray	Optical Profiler	STM
A	6	9	37
B	10	18	36

(unit: Å)

In the optical profiler and STM measurements, the minimum and maximum surface wave numbers were estimated from the reciprocal of the size of the measured area and from the reciprocal of the spatial resolution, respectively. The optical profiler scanned along the 1 mm circumstance with 1 μm resolution as to the mirro surface height, corresponding to the effective range of surface wave number from 10^{-2} to 1 μm^{-1}, the same as that for the X-ray measurements. On the other hand, the STM observed the surface area of 1 x 1 μm^2 with the spatial resolution of 10 nm, corresponding to the effective range of surface wave number from 10 to 10^3 μm^{-1}. Thus, the STM observed the different range of wave number from those by the X-ray and optical measurements. This is the reason why the X-ray and optical profiler measurements gave the similar surface roughness to each other, while the STM data gave much larger values. It is concluded that the optical profiler data reflect the property for the reflection and scattering from the hard X-ray mirror surface and can be used as a measure of the surface finish.

The PSD by the X-ray and optical profiler measurements showed a monotonical decrease in *logw(p)* vs. *logp* plot, suggesting that the mirror surface had a fractal structure as observed in the results for long SiC mirrors reported in ref.[3].

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