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Introduction to Roughness ASR Measurement Method with Mirror Roughness Measurement Example

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Abstract: In this paper attention is concentrated on one of the main factor which affects image quality of the optical elements - a surface roughness. There are presented physical background and usage of the special measuring system. Thereinafter there is presented quantitative measurement method of the microscopic surface quality with example in measuring of the PAO mirror segments scattering parameters.

Keywords: Roughness, BSDF, Mirror roughness, CASI

1. Introduction

Because of diffraction phenomenon at the entrance of the optical element, the power of the input beam is spread onto a small area instead of a single point. This spot diameter depends on the beam diameter *D* (it is the telescope aperture diameter) and the wavelength λ, so most of the power falls inside a solid angle circle of an angular radius $1.22/\lambda/D$. This phenomenon is known as the Airy disk. This is the minimum image dimension for perfect conditions and it is used as a natural scale in our discussion. If the surface is not perfect and the defects are smaller than a wavelength, some additional power will fall outside the Airy disk. This type of scattering yields to mathematical analysis, which allows computing the relation between the physical microroughness and the optical scattering. This is typical the case of a good optical surface such as a clean optical mirror.

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During manufacturing of the reflective elements is necessary to control two main parameters, which influence efficiency and image quality of the elements. They are “micro and macro” shape of the element. Therefore the quantitative research of the roughness and element surface shape is required. Our institute (Joint Laboratory of Optics) produces segmented mirrors for the Pierre Auger Observatory (PAO) fluorescent detector [1]. In this paper is presented quantitative measurement method of the microscopic surface quality with example in measuring of the PAO mirror segments scattering parameters.

2. Measuring of the surface scattering properties

The scattering properties of the surface are measured by a scatterometer with ASR method. This instrument throws essentially collimated beam on the test surface at defined incidence angle, and one or several detectors detect and capture the scattered light. These detectors are mounted on arms of the goinometer, where the scattering angle can be varied. The scattering solid angle is defined by baffles and stops.

One of the methods [2] how to determine the angle-resolved scattering is known as Bidirectional Scattering Distribution Function (*BSDF*). Relatively smooth surfaces (peak to valley distance is less than 500 $\mathring{A}$) will reflect most of the light into the zero order (the specular direction) and diffract small fractions of the light to the +1 and -1 orders. Light diffracted into the second order can be neglected for gratings with this smooth. In this case the spatial frequencies we can describe the surface by sum of gratings with frequencies f_i, which are related to the scatter angle θ_s by the one-dimensional grating equation

$$\sin(\theta_s) - \sin(\theta_i) = f_i \lambda\,, \tag{1}$$

where θ_i is incident angel and is wavelength λ of the incident light.

The *BSDF* function is the relation between the light power received within a solid angle in a certain scattering direction depending on the beam incidence angle and its power. This way determines the position and the magnitude of the diffraction orders

$$BSDF(\theta_s) = \frac{\delta P(\theta_s)}{P_i \delta\Omega_s \cos(\theta_s)}\,, \tag{2}$$

where θ_s is the scattering direction (from the normal), P_i is the power in the incident beam, δP is the power in the scattered beam inside the solid angle $\delta\Omega_s$ around the direction θ_s. Therefore, *BSDF* is physically nothing more than the redistributed energy scattered into a given solid angle. The magnitude of the first order light is determined by the sinusoidal amplitude and frequency, while the position (angle of diffraction) is determined by the grating frequency and direction. Any arbitrary surface composed of many sinusoidal surfaces should then diffract in many directions where each direction and magnitude define a sinusoidal component present on the surface. Measurements of the magnitude and direction of the scattered light can be used to calculate the amplitude and frequency of the sinusoidal components present once it is known exactly how sinusoidal gratings diffract their light. Measurement of these quantities amounts to measurement of the surface *PSD*. The *PSD* function then is calculated from the *BSDF* [2] and is a measure of the scattered power per unit of spatial frequency in units of $Å^2\mu m^2$:

$$PSD(f) = \frac{10^8 \lambda^4 BSDF}{16\pi^2 \cos\theta_i \cos\theta_s Q} . \tag{3}$$

For s-polarization, the factor Q is approximated by the specular reflectance of the surface. This function defines the surface statistics, but not the exact surface profile. However knowing the *PSD* of a given surface allows determination of *RMS*-roughness in a straightforward manner. The *RMS* roughness R_q, between spatial frequencies f_{min} and f_{max} from a one-dimensional power spectral density function PSD_{ISO} is given in equation 8. If the surface is isotropic, *PSD(f)* may be integrated around the azimuth angle to obtain an isotropic PSDISO function

$$R_q = \sqrt{2 \int_{f_{\min}}^{f_{\max}} PSD_{ISO}(f) df} . \tag{4}$$

3. Instrumentation

Instruments designed to obtain *BSDF* measurements must have either a single moving receiver or multiple receivers arrayed around the sample at scatter angles necessary for the desired measurement. Receiver consists of set of apertures and a scatter light detector. Sometimes a lens, field stop, bandpass filter and polarizing elements are added. Our measuring system SMS's CASI (Complete Angle Scan Instrument) has both moving detector and multiple-fixed detector instruments which measure scatter in the plane of incidence (defined by the incident beam and the sample normal). The receiver moves around the sample (360º around) as is shown in figure 1. This instrument can measure all angles in the scatter plane with good resolution and has a variety of apertures (solid angles). The single receiver in the CASI instrument moves in very small steps (0.007°), this way can be made the measurement very close to the specular reflection.

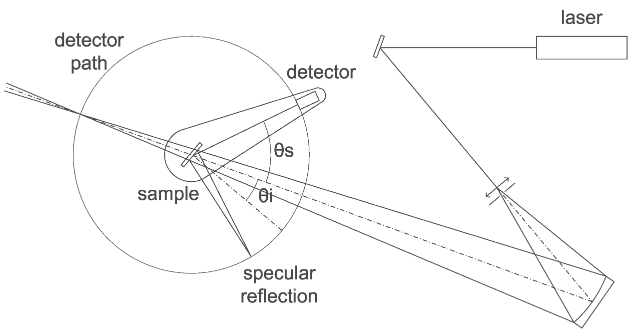

Fig. 1. Outline of the CASI system.

4. Achieved results

Our attention will be focused on scatter measuring in this section, concretely microshape parameters of the mirror segments. This way it is possible to reach a parameter, which quantitatively describes roughness characteristic of the reflective surface. Figure 2a shows the *BSDF* (Eq. 2) plot of two randomly polished mirrors. As explained above, this is a plot of scattered intensity versus angle. Looking at figure 2 we can easily see that mirror A has a higher *BSDF* function than mirror B. It indicates that mirror A scatters more light than mirror B. Without any mathematics, we can immediately note that mirror B has smoother surface than mirror A. This assumption we can support with *PSD* calculation (Eq. 3).

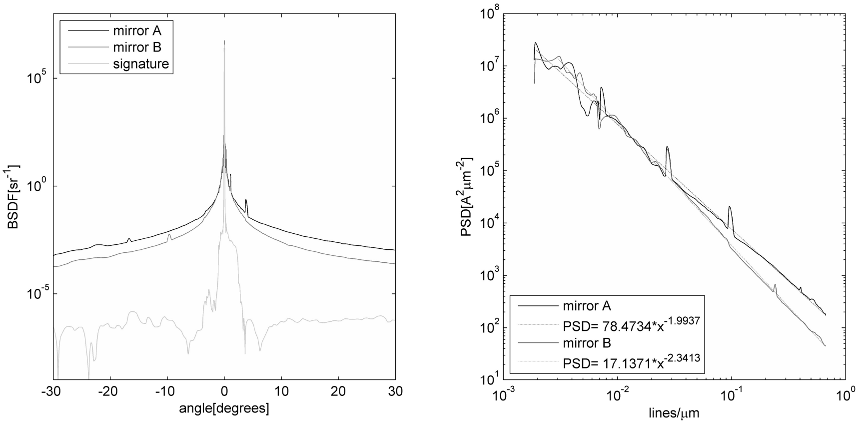

Fig. 2. a) BSDF function of the two reflective samples compared with device signature (BSDF values measured without sample), b) PSD function of the same samples.

Figure 2b illustrates mirrors A and B *PSD* functions (Eq. 3). Mirrors A and B have approximately the same scatter near the specular angle (for optical surfaces, higher scatter near specular results in a degradation of the resolution of an object). The mirror A produces more scatter then mirror B at higher angles (higher scatter at higher angles often produces glare or "noise" in an optical system). We can, therefore, deduce that the mirror A surface has a greater number of short surface characteristics then mirror B. Numerically we can describe this result with lower number in exponent in functional fit of the *PSD* functions (figure 2b). Using of the equation 8 we can characterize mirror A and mirror B reflective surfaces roughness with one quantity RMS surface roughness. For these surfaces we can obtain following values: *RMS(mirrorA)=45.3 Å* and *RMS(mirrorB)=35.1 Å*. These values we use as criterion of quality of our mirrors surface.

5. Conclusion

The measurement of the microshape quality was presented. It was shown, that we can obtain not only value of the RMS roughness in Angstroms accuracy, but also information about the surface spatial frequencies. These results help us to improve our production technology.

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