Small-angle deflectometry with coherent and incoherent illumination

Gerd Ehret, Susanne Quabis, Michael Schulz

*Physikalisch-Technische Bundesanstalt, Bundesallee 100,
38116 Braunschweig, Germany*

mailto: gerd.ehret@ptb.de

Small-angle deflectometry systems measure the form of slightly curved surfaces. Either coherent or incoherent light sources can be used in these systems. In this work, investigations of both types of light sources are shown and discussed. Both systems enable lateral resolutions in the sub-millimeter range.

1 Introduction

Deflectometry systems can be divided into large-angle and small-angle deflectometry systems [1], characterizing the relation between the beams directed to the specimen and the beams reflected to the detector. Large-angle deflectometry systems can measure complex mirror geometries with reproducibilities of a few tens of nanometers.

The principle of small-angle deflectometry, which uses a null-angle sensor, is shown in Fig. 1. We call it EADS (Exact Autocollimation Deflectometric Scanning) [2].

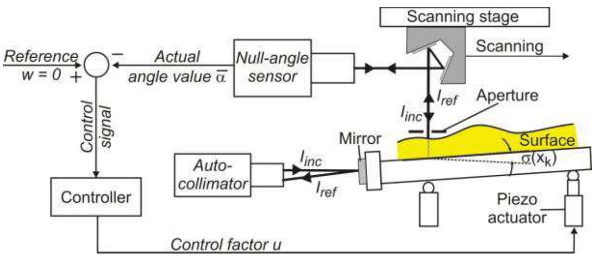


Fig. 1 *Principle of small-angle deflectometry in combination with a null-angle sensor.*

The surface under test is kept perpendicular to the scanning beam by tilting the specimen with a piezo actuator. The null-angle sensor is used as a control instrument for tilting the specimen. The surface tilt is measured by means of an autocollimator or a tiltmeter which corresponds to the slope $\sigma(x_k)$ of the surface. Integration of these measured slopes $\sigma(x_k)$ yields the surface topography $h(x_k)$. The height resolution of deflectrometric systems depends on the angle sensitivity of the sensor, which is limited by the pixel size of the image sensor, by the readout noise, by the size of the image spot and by the total image size. An open question is the influence of the degree of coherence of the illumination. Coherent illumination (e.g. by lasers) can provide high radiance, which enables short integration times. The disadvantage is that coherent illumination leads to speckle noise, which is the limiting factor in gaining small lateral resolutions. Incoherent illumination such as LED illumination avoids speckle noise, but provides only low radiance, especially for small scanning beam sizes. This leads to a low signal-to-noise ratio, which also limits the achievable lateral resolution. Measurements with coherent and incoherent illumination are presented in the following sections.

2 Measurement setup

The scheme of the developed null-angle sensor is shown in Fig. 2 and is described in detail in [3]. It uses polarization optics and an image sensor with a pixel size of 7 µm. The centroid shift must be detected with an accuracy of 0.01 pixels in order to achieve an angle sensitivity of 50 nrad (0.01 arcsec), which is sufficient for topography measurements with uncertainties in the single-nanometer range.

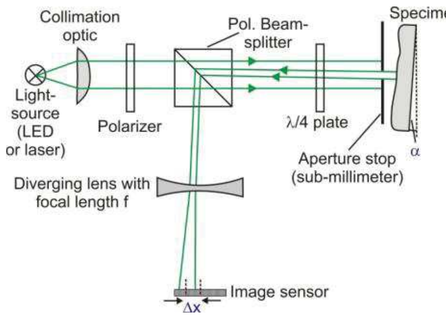


Fig. 2 *Scheme of the null-angle sensor*

A photo of the setup of the measurement system with the null-angle sensor is shown in Fig. 3.

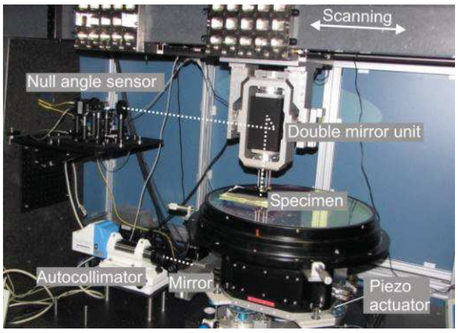
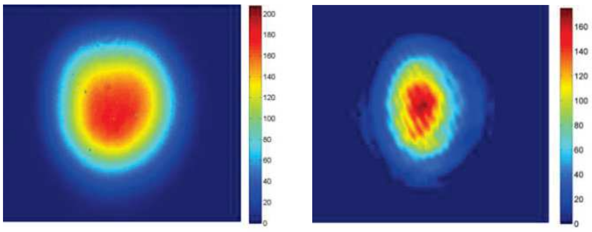


Fig. 3 *Photo of the measurement system*

DGaO Proceedings 2016 - http://www.dgao-proceedings.de - ISSN: 1614-8436 - urn:nbn:de:0287-2016-P036-3
submitted: 25.Jul.2016 - published: 8.Aug.2016

3 Measurements with LED or laser illumination

First, the point stability of the null-angle sensor using LED or laser illumination was investigated. Fig. 4 shows the spots of the scanning beam on the image sensor using a 0.6 mm aperture stop (Fig. 2). As one can see, the spot generated with laser illumination shows some interference patterns in contrast to the LED-generated spot.



(a) (b)

Fig. 4 *Spot on the image sensor. (a) LED illumination, (b) laser illumination*

By averaging several images, the standard deviation of the centroid determination can be reduced. Figure 5 shows that the standard deviation is less than 0.01 pixels by averaging over 5 images with laser illumination and by averaging over 10 images with LED illumination. Thus, both null-angle configurations can be used to measure angles with 0.01 arcsec accuracy.

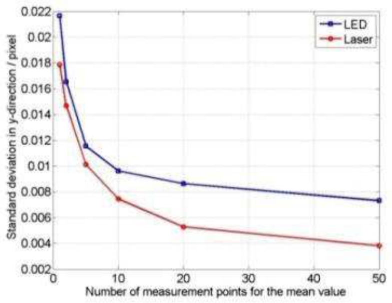


Fig. 5 *Standard deviation of coherent and incoherent illumination for determination of the centroid in the y-direction.*

The results of example measurements using laser illumination are shown in Fig. 6, which contains the topography of 7 scans measured with an aperture of 0.6 mm and a scan length of 50 mm.

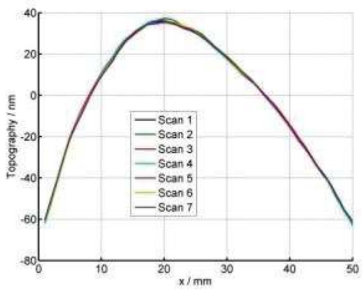


Fig. 6 *Topography of 7 scans measured with EADS and a 0.6 mm aperture.*

Figure 7 shows the standard deviations of the 7 topographies, which are less than 1 nm.

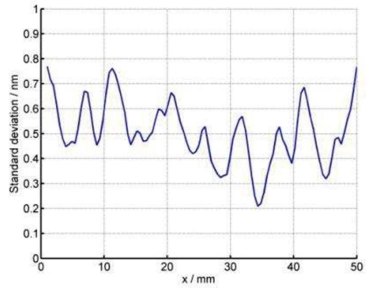


Fig. 7 *Standard deviation of the measured topographies in Fig. 6*

4 Summary

This study has shown that laser illumination can be successfully used in small-angle deflectometry, and may even get better results than conventional LED illumination. This is due to its high radiance, which is advantageous for small apertures and which also enables short integration times. Laser illumination can lead to speckle noise, although this has only a minor influence. Topography measurements with an aperture of 0.6 mm are shown. Standard deviations in the nanometer range are possible.

5 Outlook

The PTB null-angle sensor will be further investigated and optimized (length dependency, alignment). Comparison measurements with other measuring systems will be performed. In addition, we will investigate a new approach to measure the tilt of the specimen using a high-sensitivity tiltmeter with an angle resolution of 0.2 miliarcsec, which is superior to common autocollimators.

References

[1] G. Ehret, M. Schulz, M. Stavridis, C. Elster: Deflectometric systems for absolute flatness measurements at PTB. Measurement Science and Technology: 23 (2012), 9, 094007-1 - 094007-8

[2] M. Schulz, G. Ehret and A. Fitzenreiter: Scanning deflectometric form measurement avoiding path-dependent angle measurement errors. Journal of the European Optical Society: Rapid Publications: 5 (2010), www.jeos.org/index.php/jeos_rp/article/view/10026/596

[3] Gerd Ehret, Susanne Quabis, Michael Schulz, Birk Andreas, Ralf D. Geckeler: Sensorentwicklung zur deflektometrischen Topografiemessung mit sub-Millimeter Aperturen, DGaO proceeding 2013.