# Investigation of the two-dimensional power spectral density (2-D-PSD) and rms-roughness Sq on polished optical surfaces

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**Abstract:** Current standardisation of defects and quality of optical surfaces as ISO 10110 are mainly based on one-dimensional scanning methods. However, new instruments as confocal microscopes, white-light interferometers or atomic force microscopes (AFM) provide the possibility to generate three-dimensional surface profiles. Out of the three-dimensional surface data it is possible to calculate two-dimensional power spectral density. In theory the 2-D-PSD directly allows conclusions to be drawn about the surface properties like anisotropic textures or polish quality. Within the scope of this presentation ten optical glass surfaces are investigated with an AFM. The gained data are analysed on the surface parameters rms-roughness Sq and 2-D-PSD. In comparison with previous Sq-values measured by white-light interferometer the Sq-values measured by AFM show clear deviations. Different 2-D-PSD-graphs are shown on the poster and the connection to surface topographies are visualised by AFM pictures. Due to the 2-D-PSD data the mentioned connections between the graphs and anisotropic textures are shown.

## Approach:

Ten planar optical plates are investigated and Sq-values were readout with the AFM-Software. The 2-D-PSD-Data is calculated with the Software *WSxM 4.0 Develop of Nanotec Electronica S.L.* [1] 2-D-PSD.

## Theory:

The root-mean-square roughness parameter Sq is generally and also by the AFM-Software [2] calculated according to formula (1). In there $M$ and $N$ are the number of values in $x$- and $y$-direction. $z\,(x_k,y_l)$ stands for the particular values.

$$S_q = \sqrt{\frac{1}{MN}\sum_{k=0}^{M-1}\sum_{l=0}^{N-1}\left(z(x_k,y_l)\right)^2} \qquad \textbf{(1)}$$

Power Spectral Density (PSD) provides the spectrum of the spatial frequencies of the surface and is given in inverse units of length [3]. The PSD contains information about spatial frequencies from 0 to ∞ means from infinite flat surface to a surface with infinite small textures. In mathematical sense the PSD is a squared Fast Fourier Transformation (FFT) of the surface and is calculated according to formula (2), [3].

$$PSD(f_x,f_y) = \lim_{L\to\infty}\frac{1}{L^2}\left|\int_{-L/2}^{L/2}\int_{-L/2}^{L/2} h(x,y)\times\exp\left[-2\pi\, i\left(f_x x + f_y y\right)\right]dx\,dy\right|^2 \qquad \textbf{(2)}$$

## Investigation and results:

First the different kinds of data filters which are available in the AFM-Software are analysed. The polynomial-fit-filter was applied to all measuring-data before calculating the PSD-graphs and Sq-values. This was necessary to remove the construction-related waveform of the data. After using this filter the data could be visualized as shown in Figure 1.

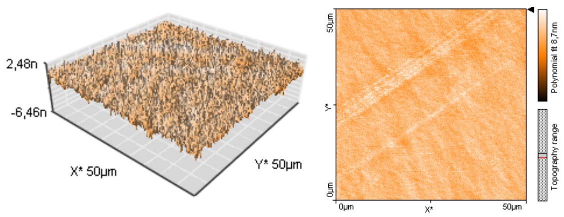


*Figure 1: 3-D-plot (left) and colour-plot (right) of the measurement-data of one AFM-Scan on the plane optical surface. Attention should be paid to the dimensions as the values of the z-axes are given in nm and the values of the x- and y- axes are given in µm.*

The Sq-values gained out of the AFM-measurements are shown in Figure 2. rms-values which are measured by white-light-interferometer are drawn in the same chart. A comparison of those values turns out to be very difficult because the measurements with the white-light-interferometer were done on an area of **360 µm × 270 µm** and the AFM-scans only on **50 µm × 50 µm**. The standard deviation within the Sq-values is relatively large because only a few measurements per sample are done. The Sq-values differ more among each other than the rms-values because local roughness affects the small scan-sector of the AFM-scan more than the relatively large scan-area of the interferometer.

Figure 3 shows three different AFM colour-plots which are measured on the same kind of optical surfaces. They show clear differences in their texture hence the surface of sample 1 is more uniform and the surfaces of sample 2 and 3 show directional surface properties. Out of these AFM-data 2-D-PSD graphs are calculated and visualized in Figure 4. The software mentioned above calculates fitting-curves of the 2-D-PSD-Graphs which are drawn in the same Figure.

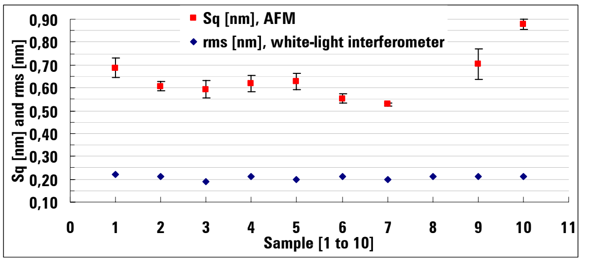


*Figure 2: Comparison of the Sq - values (AFM) and rms - values (white light - interferometer). The error bar on the Sq-values gives the standard deviation within the measurement values.*

A closer look on the slope of the fitting curves shows clear differences between the three samples. The 2-D-PSD-Graph of sample 1 shows the slightest decrease and the slope of sample 3 the steepest. A closer investigation of the profile perpendicular to the directive textures show that the "scratch" in sample 3 is deeper than the "scratches" in sample 2.

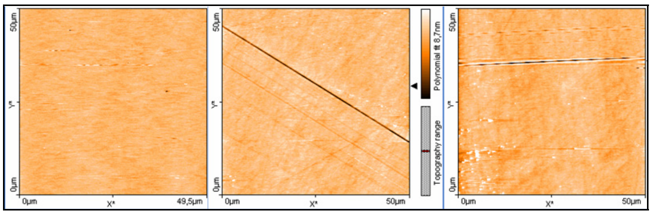


*Figure 3: Colour-plots of AFM-scans on the plane optical surface. Sample 1 (left), sample 2 (middle) and sample 3 (right).*

That yields to the assumption that the steeper the fitting of the 2-D-PSD curves appears the more directive the related surface texture is. This perception is confirmed by additional measurements.

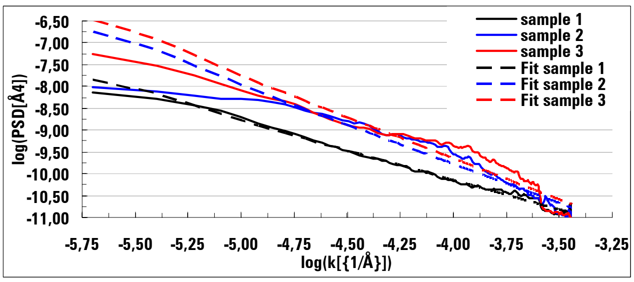


*Figure 4: 2-D PSD-Graphs and fitted curves calculated out of the AFM-data in Figure 3.*

One important hint has to be added: The Utility of the AFM for this kind of measurements is limited hence it is very time intensive to scan the surface of the sample line per line with the AFM. Quicker approach should be possible with a white-light interferometer.

## References:

[1] WSxM 4.0 Develop 12.3-Software, I. Horcas, R. Fernandez, J.M. Gomez-Rodriguez, J. Colchero, J. Gomez-Herrero and A. M. Baro: Rev. Sci. Instrum. 78, 013705, 2007; accessed via http://www.nanotec.es/ on 24.09.2008

[2] Nanosurf AG, *Operating Instructions easyScan 2 AFM Version 1.6*, Liestal/Schweiz: Nanosurf AG; 2007

[3] Duparré et al., *Surface characterization techniques for determining the root-mean-square roughness and power spectral densities of optical components*, Jena: Applied Optics, 2002