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# Influence of the inhomogeneity of the field of view on the measurement of surface texture in optical surface topography measuring instruments

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**Abstract**

Three-dimensional (3D) optical microscopy, such as coherence scanning interferometry (CSI), confocal microscopy (CM) and focus variation instruments, is increasingly applied in various academic and industrial areas for surface topography measurements as it offers unique advantages including high throughput, areal, noncontact and non-destructive measurements. However, the ability and capability to accurately reproduce topographical features of a surface under test is quite challenging due to the complexity of the interaction between light and surface. Experimental investigations show that the influence of the inhomogeneity of the field of view (FOV) of a microscope objective on the measurements of surface texture is different for different types of surfaces.
In this paper an experimental method to investigate the inhomogeneity of measured roughness parameters in the FOV of microscope objectives in confocal microscopy has been developed. Two kinds of surface textures, i.e. one very challenging surface with high spatial frequency and larger local slopes and the other one with moderate local slopes have been measured and compared. The measurement results show that the Sq and Sa values of the challenging surface evaluated by the full FOV have deviations of 50% in comparison with the corresponding reference values due to the inhomogeneity of the FOV. The evaluation area for calculating the surface texture height parameters within the FOV needs to be chosen carefully and individually in order to obtain the parameters with low measurement uncertainty.
It is expected that this method can also be applied to investigate and quantitatively evaluate the systematic measurement errors induced by the inhomogeneity of the FOV of microscope objectives in CSI and FV instruments.

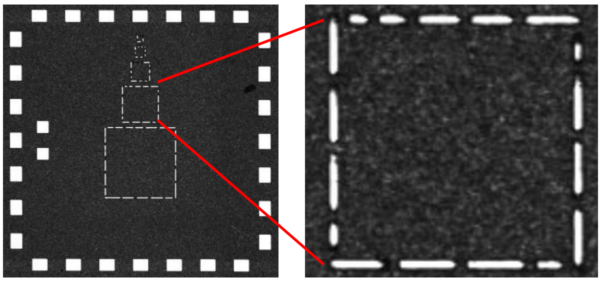
Keywords: Surface texture metrology, optical topography measuring instrument, measurement uncertainty, inhomogeneity, field of view

## 1. Introduction

Three-dimensional (3D) optical microscopy, such as coherence scanning interferometry (CSI), confocal microscopy (CM) and focus variation (FV), is increasingly applied in various academic and industrial areas for surface topography measurements as it offers unique advantages including high throughput, areal, noncontact and non-destructive measurements [1-3]. However, the ability and capability to accurately reproduce topographical features of a surface under test is quite challenging due to the complexity of the interaction between light and surface [4-6]. Currently a ISO standardised calibration framework [7, 8] based on seven common metrological characteristics (MC) of optical instruments, including the amplification coefficient, linear deviation, flatness deviation, measurement noise, topographic spatial resolution, x-y mapping deviations and topography fidelity, for surface texture metrology has been newly developed, in which besides the six well-known geometrical MCs, topography fidelity is a newly introduced MC aimed at accounting for all the remaining systematic errors not captured by conventional geometrical calibration when measuring complex topographies [9], including the overshooting caused by multi-scattering and/or multi-reflection, object- and measuring-principle-dependent different performance in x- and y-directions of the optical instruments and inhomogeneity of the field of view (FOV) of the used objective and so on. However, the aforementioned standard does not specify default material measures or methods for investigating the various aspects of topography fidelity. Using certain material measures, such as rectangular gratings with different pitches, sinusoidal [10, 11] or rectangular [12] chirp standards researchers have achieved some results through numerical simulation [4, 13-16] and experimental methods [17-18]. However, the results do not quantitively correlate with the measurement uncertainty contribution for specific surface texture measurement tasks. In this paper an experimental method to investigate the inhomogeneity of the FOV of microscope objectives in confocal laser scanning microscopy for surface texture measurement has been developed. The inhomogeneity of the FOV, in this context, refers to whether the same topography images can be obtained when the same surface is measured in the different positions within the FOV. Two kinds of surface textures, i.e. one very challenging surface with high spatial frequency and larger local slopes and the other one with moderate local slopes have been measured with the proposed method and the measurement results were compared and discussed.

## 2. Investigation of the inhomogeneity of the FOV of a CLSM for surface texture measurements

An ARS f2 areal surface texture sample [19], a very challenging silicon lapped surface with high frequency components and larger local slopes, was selected for testing the measurable slope capability and the performance of various optical topography measuring instruments. Figure 1 shows the layout of ARS f2 with different measurement fields whose inner areas range from 32 µm x 32 µm to 512 µm x 512 µm. The measurement field of 256 µm x 256 µm was measured with a 50x objective by a commercial confocal laser scanning microscope (CLSM) and within this field five representative positions were characterized using AFM.



(a) Measurement fields of ARS f2 with marking frames

(b) Measurement field 256 µm x 256 µm with marking frame

Figure 1. Areal surface texture sample ARS f2

### *2.1. Comparison of the Sq values measured by a CLSM and AFM*

The AFM reference measurements were performed on an ARS f2 at VSL national metrology institute with a Dimension 3100, which was calibrated by height and lateral standards. The scan field size is 30 µm x 30 µm (512 x 512 pixels) with a scan speed of 3 µm/s.

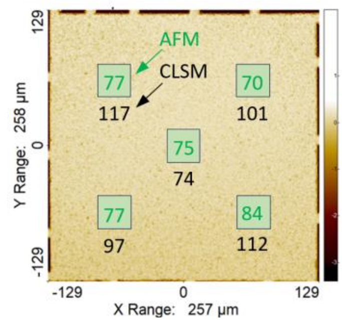



Figure 2. Comparison of Sq values measured by CLSM (50x, NA 0.95) and AFM on an ARS f2 sample (unit: nm).

Figure 2 shows the topography image of the ARS f2 measured by the commercial CLSM with 50x objective, whose numerical aperture (NA) is 0.95 and the FOV is 258 µm x 258 µm. Reference measurements using AFM at 5 measurement positions on the sample within the FOV are illustrated. Cross-correlation method was used to find the exact positions of the AFM measurements on the optical measured topography. Height parameters Sa and Sq of the surface texture measured by AFM and CLSM were evaluated. As shown in Figure 2, numbers (rounded) in green show the Sq values of AFM measurements, and that in black show the evaluated Sq values of CLSM measurement at the same positions with the same size as AFM measurements. It can be seen that in the middle of the FOV, both measurements have good agreement, however, the Sq values measured by CLSM and AFM at the other four off-centre positions show large differences with each other. The maximum difference of the Sq value is about 31 nm, as shown in Figure 2 at the upper right position of the FOV.

However, with these comparisons only the measured positions can be compared. The homogeneity of the FOV can be investigated quantitively through this comparison only if the entire FOV is measured by AFM. This process is very time-consuming and therefore may introduce measurement uncertainties, such as thermal drift, tip wear, which can complicate the comparison.

### *2.2. Experimental method to investigate the inhomogeneity of the FOV of a CLSM*

To investigate the homogeneity of the FOV without great measuring effort with AFM by measuring a large size or many small areas on the sample, an experimental method by shifting the sample surface under microscope has been developed. After comparing with reference measurement, it is supposed that a small region of the surface - the test region with e.g. 30 µm x 30 µm size - in the middle of the FOV can be measured by a 3D optical microscope with low uncertainty, then shift this test region with specified step length to different positions within the FOV. By comparing the measured results of this test region at different positions of the FOV, the homogeneity of the FOV can be quantitively determined.

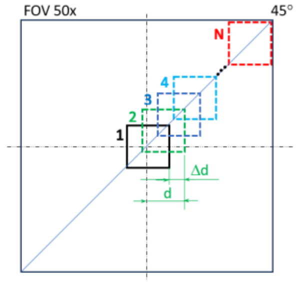



**Figure 3.** Schema of the measurement steps to investigate the inhomogeneity of the FOV of a CLSM, *Δd is the shift of each step and d is the distance from the right border of the shifted test region to the centre of the FOV.*

Figure 3 illustrates the measurement steps (1 to N) along the 45° direction using the aforementioned CLSM with 50x objective. Firstly, the sample surface needs to be aligned and centred under the microscope and the first measurement need to be performed. The topography image of the black square (30 µm x 30 µm size) can be cropped from the full FOV image and is used as the test image. Then the sample is shifted with a distance of *Δd* = 10 µm (or 5 µm) along x- and y- direction to make the test region at the second position as shown in Figure 3. The distance *d* corresponds to the half width of the investigated measurement size determined by the position of the test region. N steps need to be performed until the test region lies very close to the border of the FOV. For each step, one full FOV topography image will be obtained. To extract the topography image of the test region of each step, a cross-correlation method was applied to match the test image to the full FOV images of each step.

Measurement steps along different directions or randomly distributed positions can be performed to investigate the homogeneity of the FOV using the optical instrument itself, which measures the surface much faster than an AFM.

## 3. Experimental results of the inhomogeneity of the FOV

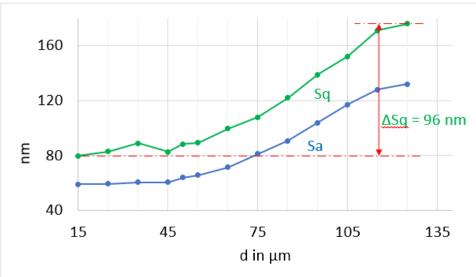
Two kinds of surfaces have been investigated by the CLSM with 50x objective. One is the ARS f2 as above mentioned in Section 2. The second one is a milled technical surface having similar hight parameters but with moderate frequency components. As prior knowledge has been obtained, that the upper right corner of the FOV has worse performance than other positions by characterisation of the instrument, only measurements along this 45° direction are shown in this paper. The shifts Δd are firstly three times 10 µm, then two times 5 µm and finally seven times 10 µm. Two times small steps with 5 µm shift were chosen, corresponding to the measurement size of 90 µm to 110 µm, where the height parameters start to change significantly for ARS f2 measurements, to have more detailed information about the changes. The last step approaches to the top-right corner of the FOV with d = 125 µm, where the maximum deviations of surface texture parameters of ARS f2 measured by the 50x objective can be obtained.

Figure 4 shows the evaluated Sa and Sq values of the test region of the two samples measured at different positions within the FOV respectively.

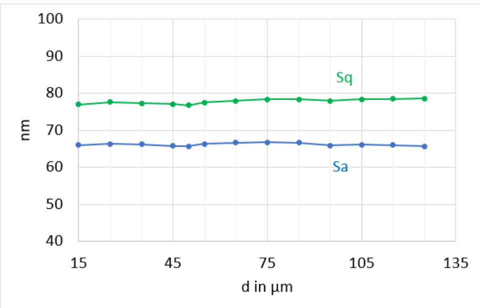
It can be seen from Figure 4(a) that the Sq or Sa values of test region of ARS f2 keep stable in the measurement range of 90 µm (d = 45 µm) within the FOV while change significantly when it is measured outside of the 90 µm x 90 µm range. The Sq values measured at the first and the last measurement positions are 79.8 nm and 176 nm respectively, with a relative change of 121%.

However, Figure 4(b) shows the evaluated Sq or Sa values of the test region of the milled surface at different measurement positions, where Sq exhibits a very slight increase of 1.6 nm within the whole FOV.

The measurement results of the two samples reveal that the influence of FOV inhomogeneity is object-dependent.




(a) Sa and Sq values of the central 30 µm x 30 µm region of the ARS f2 surface measured at different position along 45° direction within the FOV

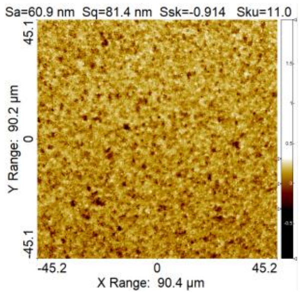



(b) Sa and Sq values of the central 30 µm x 30 µm region of the milled surface measured at different position along 45° direction within the FOV

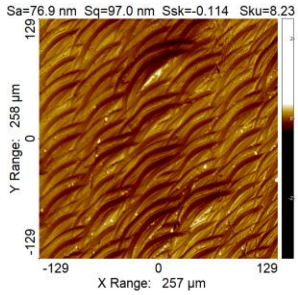
**Figure 4.** Influence of the inhomogeneity on the measured surface textures.

## 4. Discussion

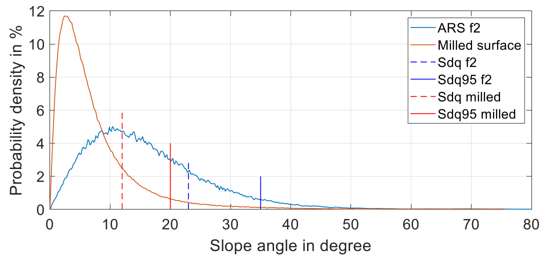
As the test region can be measured with low uncertainty in the central range of the FOV, it can be assumed that the challenging sample surface features can be resolved and the local slopes can be measured with the used 50x objective with a NA of 0.95. The NA of 0.95 corresponds to a maximum measurable slope ($\theta max$) of 71.4°. Figure 5 (a) and (b) show the measured topography images of the two samples with image size of 90 µm x 90 µm and 258 µm x 258 µm respectively. And Figure 5 (c) shows the corresponding slope distributions of the two measured surfaces. The Sdq [20] values are 12° and 22° and the 95% of the local slopes (Sdq95) are under 20° and 35° respectively, which are much smaller than the maximum measurable slope of the applied objective.




(a) Topography image of an ARS f2 measured by a CLSM with 50x objective (NA 0.95), 90 µm x 90 µm




(b) Topography image of a milled surface measured by a CLSM with 50x objective (NA 0.95), full FOV




(c) Slope distributions of the measured ARS f2 and the milled technical surfaces (ARS f2: Sdq 22° and Sdq95 35°, milled surface: Sdq 12° and Sdq95 20°)

**Figure 5.** Measured topographies of the two samples and the corresponding slope distributions.

Taking into account the measuring principle of the applied CSLM [2], which uses scan mirrors to move the laser across the sample, we assume that the scanning angles of the scan mirrors influence the maximum measurable slope of the objective. When the scanning angle increases, i.e., when scanning occurs near the border of the FOV, the maximum measurable slope of the objective decreases. Surface features with larger local slopes, such as the ARS f2 surface, which can be measured in the central region of the FOV with very low uncertainty, may not be accurately captured near the border of the FOV. This can lead to measurement artefacts, such as overshooting, which result in larger height parameters. However, how the scanning angles will influence the slopes to be measured needs to be further investigated in the next step.

Another point to consider is the size of the test image to be measured and the step length. On one hand both should be small enough to reveal the inhomogeneity of the FOV, however, on the other hand the test image should include most of the features of the surface being measured. Currently it is recommended that the length and width of the test image should be at least 5 to 6 times of the autocorrelation length of the surface.

## 5. Conclusions

A simple experimental method to investigate the inhomogeneity of the FOV of optical topography measuring instruments for surface texture metrology has been proposed, which has the advantages that with only a small size of the AFM reference measurements, 1) It can be determined if the optical measurement results are reliable; 2) The influence of the object-dependent inhomogeneity of the measurement results can be determined and the size to determine the surface texture parameters can be limited for a negligible uncertainty contribution. This experimental method addressed one of the open questions regarding the metrological characteristic topography fidelity, thus makes it possible to evaluate the measurement uncertainty contribution caused by the inhomogeneity of the FOV in optical surface texture metrology.

Two kinds of surface examples have been investigated and the results show that the influence of the inhomogeneity of the FOV is object dependent.


### Acknowledgements

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