An investigation of the defocus behaviour of an optical microscope used for high precision length metrology

Rainer Köning, Jens Fluegge and Harald Bosse *

* PTB Braunschweig, WG 5.21 Length graduations, Bundesallee 100, 38116 Braunschweig, Germany

mailto:rainer.koening@ptb.de

.

1 Introduction

At the vacuum interference comparator of the PTB, the Nanometer Comparator [1], the defocus influence of the optical microscope on the line position of graduation lines led to increased expanded measurement uncertainties (coverage factor k =2) for line scale measurements of a few 10 nm. Therefore, in order to reach the desired measurement uncertainties of only a few nanometres, the uncertainty contributions of the microscopic position detection had to be reduced significantly.

2 Microscope

Figure 1 shows a schematic of the microscope. The illumination is provided by a cold light source with integrated green filter and fed through an incoherent fibre bundle to the illumination system. Its optics realises a Köhler illumination as required by the telecentric, long distance but low aperture objectives [2] used. The illumination optics has been optimised by means of optical design software to provide an intensity in the objective's back focal plane, which is as homogenous as possible. A pellicle serves as beam splitter because the objectives are not corrected for infinity. The image is detected by a progressive scan CCD camera [3].

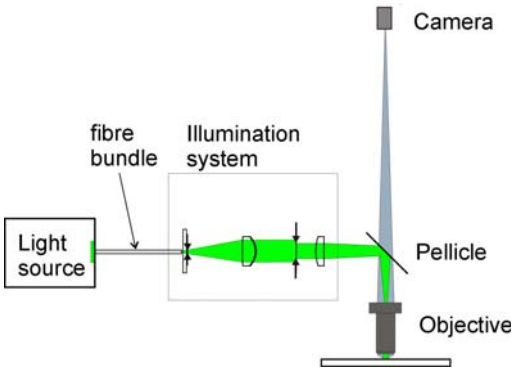

Figure 1 *Schematic of the optical microscope*

3 Test setup

In order to characterise the optical microscope and identify the source of the observed defocus influence on the position of the line structures the test setup shown in figure 2 was realised. In order to achieve the desired uncertainty level the optical

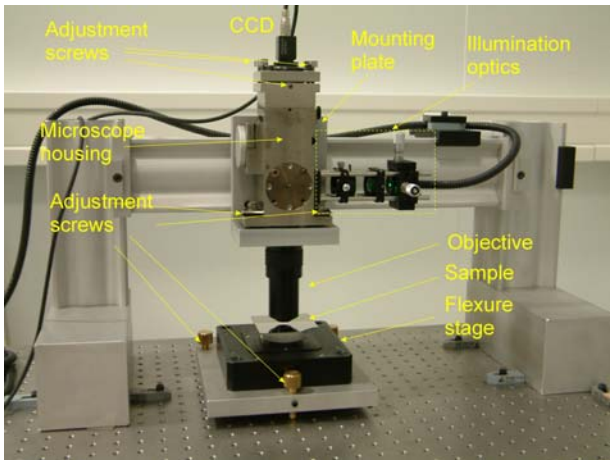

Figure 2 *Image of the test setup*

microscope needs to be well integrated in the mechanical setup. The influences of temperature changes and mechanical vibrations on the length measurements have to be minimised. Therefore the rigid microscope housing is made out of super invar. It rests with three adjustment screws upon an L-shaped mounting plate, which itself is screwed to a bridge. The orientation of the microscope and therefore the orientation of its optical axis relative to the sample surface can be aligned by the three adjustment screws. The optical components of the microscope were aligned with respect to each other and centred to the optical axis by means of an alignment laser, which was mounted instead of the camera on top of the microscope housing. Photo masks served as test samples. They were supported by gauge blocks so that the sample surface is approximately located in the focal plane. A six axis controlled precision flexure stage provided the required accurate lateral and vertical motion of the sample used for characterisation of the microscope.

4 Results

Figure 3 shows the variation of the line position (top) and the line width (bottom) of a nominally 10 μm wide line as function of the z-deviation from the focus plane using the new illumination system and an optimised alignment procedure. Each point

represents an average value calculated out of 16 images. The error bars represent the 2σ interval of the associated repeatability, which is approximately 0.5 nm. It was observed that the focus position depends on the used focus criterion. We chose the minimum of the change of the line position due to a defocus, because we are interested in high precision measurements of the line position.

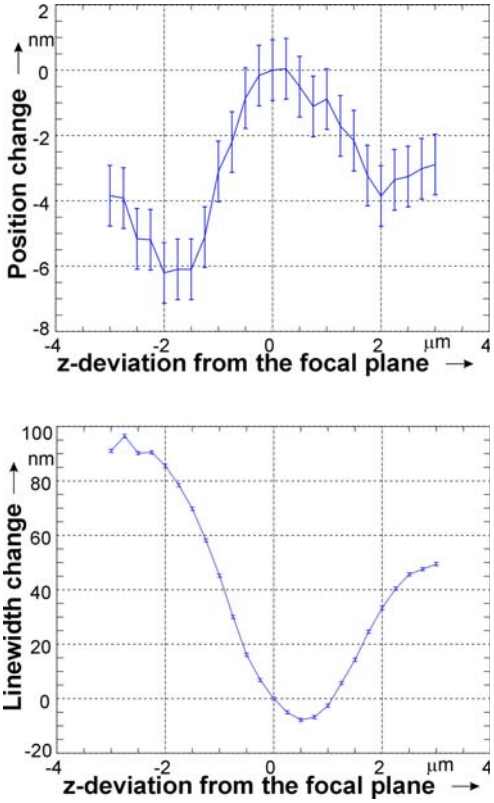

Figure 3: *Dependence of the line position (left) and the linewidth (right) on the deviation of the sample's z-position from the focal plane.*

The defocus influence on the position of a line remained smaller than 6 nm while the sample was moved from -3 µm to 3 µm with respect to this focus position. It is obvious from the lower diagram, that the minimum observed line width is not located at the same z-position. This behaviour and the principal dependence of the defocus influence were confirmed by a comparison between the results of our microscope and a commercially available linewidth microscope [4]. The influence of the selected threshold on the variation of the linewidth is shown in figure 4 for two different alignment states of the microscope. The expected threshold value of the isofocal points, which appear in the line profiles, is close to 0.5. In both cases the defocus dependencies are minimal at this value. However, in the top diagram, in this case, a linear

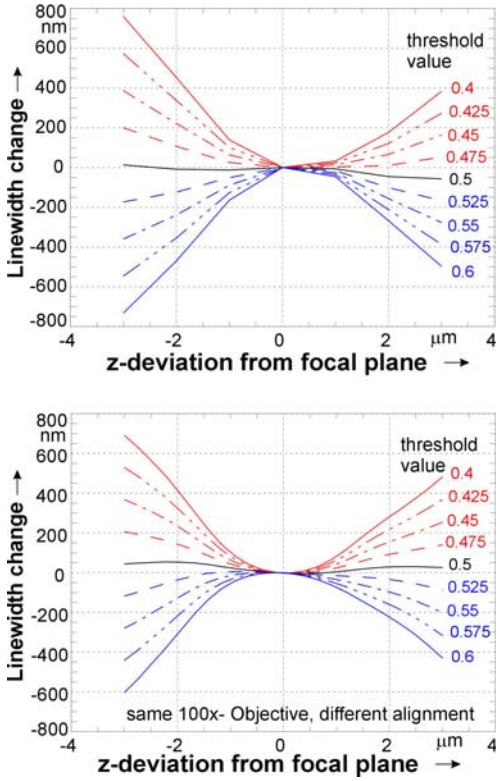

Figure 4: *Influence of the threshold on the defocus dependence of the linewidth at different alignments.*

dependence was observed while in the bottom diagram a quadratic dependence appeared.

5 Conclusions

The two related curves of the position change with the defocus, which are not shown here, also exhibited significant differences. Therefore, it is likely that the defocus curves of the position or the width of a line calculated for different thresholds allow to diagnose or to verify the alignment state of the optical microscope. The optimised microscope was remounted and realigned at the Nanometer Comparator again and used in line scale measurements. The reproducibility of these measurements decreased from several ten nanometres to below 1 nm [1].

6 References

[1] R. Köning et al.: Proc SPIE 6518 (2007), 65183F

[2] Nikon measurement objectives, magnification: 20x - 100x, working distance: 49 mm - 4 mm and numerical aperture: 0.4 - 0.75 were used

[3] Sony xc-55BB, remote head, pixelsize 7.4 µm × 7.4 µm, total power consumption 3 W.

[4] Leica INN, located in the ultra-high resolution microscopy group of the PTB