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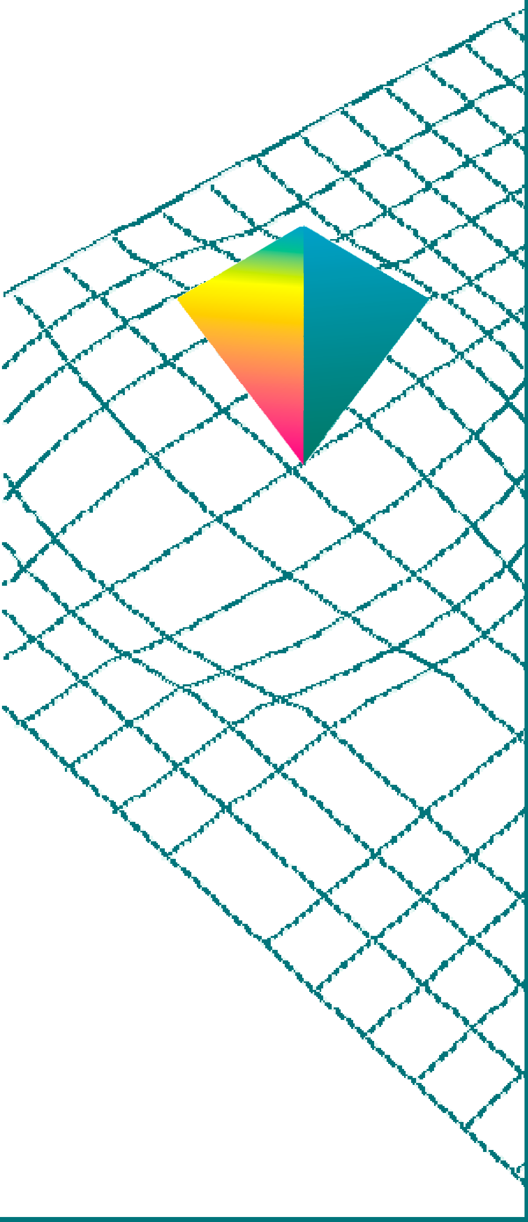
Mechanical Engineering from Macro to Nano



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Gaoliang Dai / Frank Pohlenz

Micro and nano dimensional metrology on the basis of nano measuring machine

ABSTRACT

On the basis of nano measuring machine, nano and micro dimensional metrology using scanning probe microscopes (SPMs) and metrological profilometers is presented. An overview on calibrations of nano structures, such as step height, one and two dimensional grating, feature width, nano roughness and geometry of nano hardness indenter, and micro structures, such as micro groove, micro roughness and geometry of macro hardness indenter, is given in this paper.

INTRODUCTION

Quantitative dimensional measurements of nano and micro structures are increasingly in demand following the rapid developments in semiconductor industry, precision engineering industry, micro system techniques and material science. The size of these nano and micro structures spans from nanometres to hundreds of micrometres. To fulfil these demands, advanced microscopy techniques as for instance scanning probe microscopy (SPM) and scanning electron microscopy (SEM) have been well developed in the recent decades.

However, even nowadays the capabilities for accurate dimensional measurements of nano and micro structures are still insufficient due to several principal limitations:

- Many microscopes are serving as “vision tools” only because of two reasons. Firstly, the instruments suffer from a lack of effective dimensional measurement sensors. For instance, SPMs use the voltage applied to the piezo transducers (PZT) as position measuring sensor, and consequently suffer from the nonlinear and creep behaviours of the PZTs. Secondly, many microscopes have not been sufficiently calibrated due to, for example, the lack of accurately calibrated nano and micro dimensional standards.
- Probe techniques of most microscopes are lacking of true 3D or even quasi-3D measuring capabilities.
- The measurement range of most microscopes is limited, and/or high resolution is only obtainable within a small measurement range due to the limitation of the pixel number.

- A gap between nano and micro dimensional metrology exists. Although nano structures can be well observed and measured with resolutions even at atomic level using currently available SPM techniques, it is still difficult to fulfil 3D measurements of micro structures e.g. micro gears.

In order to further expand the application capacity of the SPM method, on the basis of nano measuring machine (NMM), PTB has set up a metrological large range SPM and a metrological profilometer. Calibrations of versatile nano and micro structures have been carried out.

INSTRUMENTATION

Three metrological SPMs referred to as the Veritekt B, the Veritekt C and a large range SPM (LR-SPM), have been set up at PTB. The Veritekt B and C have a capable measurement volume of 70 µm × 15 µm × 15 µm (x, y, z); whereas the LR-SPM has a capable measurement volume of 25 mm × 25 mm × 5 mm (x, y, z). The operation principles and instrumentations of these instruments have been published elsewhere [1-3]. In this paper the LR-SPM (see Fig.1) will be highlighted and discussed in more details.

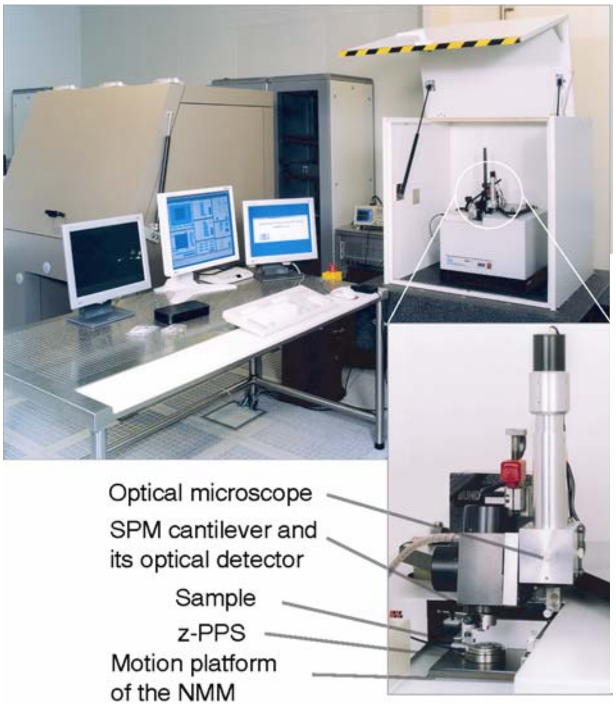


Fig. 1. Photo of the LR-SPM setup.

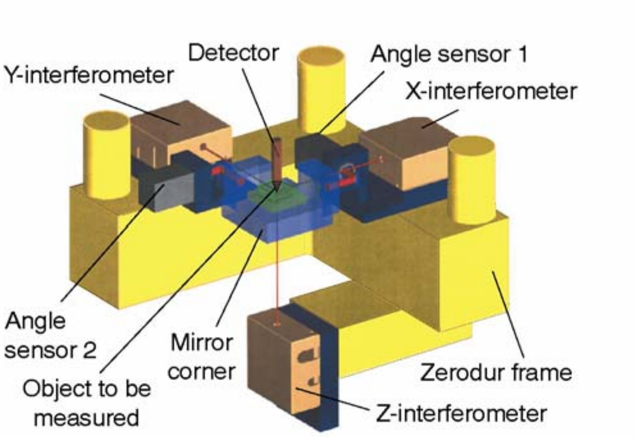


Fig. 2. Schematic principle of the metrological frame of the LR-SPM.

The LR-SPM is based on the scanning sample principle. The image is formed by monitoring the deflection of the cantilever as the sample is scanned beneath the tip. In order to obtain the large range scanning capability, the sample is moved by a combined motion system which consists of a fast z-piezo positioning stage (z-PPS) and a ball-bearing positioning stage (NMM). The motion servo controllers of the z-PPS and the NMM are executed in parallel. As a benefit, both a large measurement range and a high measurement speed can be achieved using such a configuration. The topography of the surface, derived from the position of the sample, is traceably measured by embedded laser interferometers along the x, y and z-axes. The specifications of the LR-SPM are summarised in TABLE 1.

Measurement volume	25 mm × 25 mm × 5 mm (x, y and z)
Resolution of interferometers	0.08 nm (x, y and z)
Noise level along z-axis	2~3 nm (peak-valley)
Sample size	Up to 50 mm × 50 mm × 10 mm (x, y and z)
Scanning speed	Up to 50 µm/s, typically 20 µm/s
Fast scan direction	Any direction in xy-plane (software configurable)
Dimension of scanning image in pixels	No limit
Dimension of scanning image in millimetres	Up to 25 × 25 mm^2 without the need of stitching procedures
Nonlinearity of interferometers	< 0.3 nm with applied Heydemann correction (x, y and z)
Traceability	Laser interferometer whose laser has a frequency stability of better than 2×10^{-8} and which is calibrated to an I_2–stabilised He-Ne laser
Scanning modi	Single line (profile) and scans (SPM)

TABLE 1. Summary of the specifications of the LR-SPM.

The metrological frame of the instrument (see Fig.2) mainly consists of a metrological base (Zerodur frame), a mirror corner and the measurement systems including three interferometers and two angle sensors. The mirror corner, which comprises three high precision planar mirrors attached orthogonally to each other, is fixed to the motion stage of the NMM. This motion stage is moved by ball bearing guidances driven by electrodynamic motors (not shown in Fig.2). All six degrees of freedom of the motion stage are measured directly by interferometers (with a resolution of 0.08 nm) and angle sensors (with a resolution < 0.01 arcseconds). Based on these measurement values, a servo controller is addressed by the NMM controller for controlling its position and orientation. Due to the fact that during the measurement process, the SPM probe tip and therefore the measurement point is always located at the intersection point of the three interferometer beams this arrangement reduces the Abbe-error to a minimum.

In order to further expand the application capacity of the LR-SPM, a diamond stylus detector has been implemented as an alternative probe head to the LR-SPM, and consequently a new metrological stylus profilometer is built up. The schematic diagram of such a profilometer is shown in Fig.3. In its configuration, the diamond stylus detector (RFHTB-50, Mahr Company) is applied to sense samples in contact mode. The stylus tip is used as a zero detector like a SPM cantilever. The position change of the stylus tip is detected by its embedded inductive sensors. An analog signal representing the tip position is fed from a preamplifier to a DSP system after being analog-to-digital converted. In the DSP, the tip position is compared to a given home position, generating a motion command signal fed to the NMM. In such a way, the sample is moved by the NMM along x, y and z-axes, and the stylus tip is always moved towards its home position during the measurement. The measurement results are derived by combining both the stage position of the NMM and the position of the stylus tip.

This NMM-based stylus profilometer has an optimised metrological performance. Firstly, it is capable of accurate and traceable dimensional measurements with a resolution of 0.08 nm along x, y, and z-axes using the embedded three laser interferometers of the NMM. Secondly, the tip of the stylus probe is positioned at the intersection of the three interferometer measurement beams, and the deviation is less than 0.5 mm in practice. As the benefit, the Abbe error, a significant important error source in the dimensional metrology, is expected to be less than 0.5 nm. Furthermore, the "true" stylus tip position can be calculated as it is calibrated with respect to the z-interferometer of the NMM in situ, in a similar way as the LR-SPM [1].

Although commercial available stylus profilometers are good at roughness measurements, they have only limited capability in form and contour measurements due to e.g. limited measurement range along the z-axis as well as the guidance and measurement errors of their positioning system. In contrast, this NMM-based stylus profilometer is able to achieve accurate roughness measurements as well as the measurements of the contour and form of micro structures.

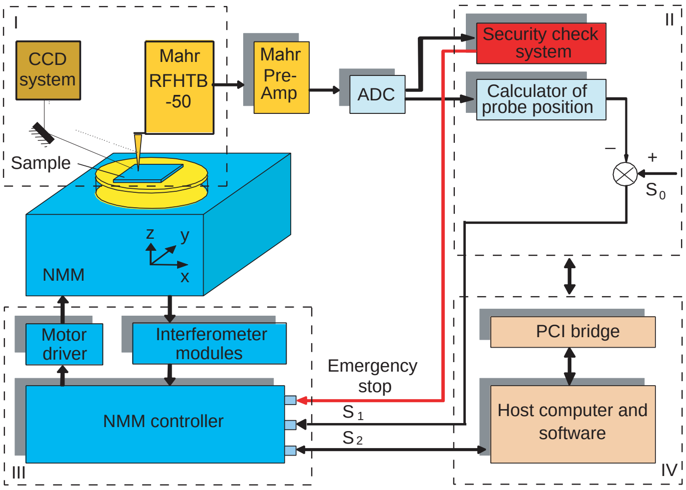


Fig.3. Schematic diagram of a new developed metrological stylus profilometer

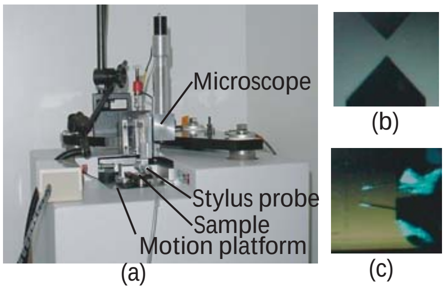
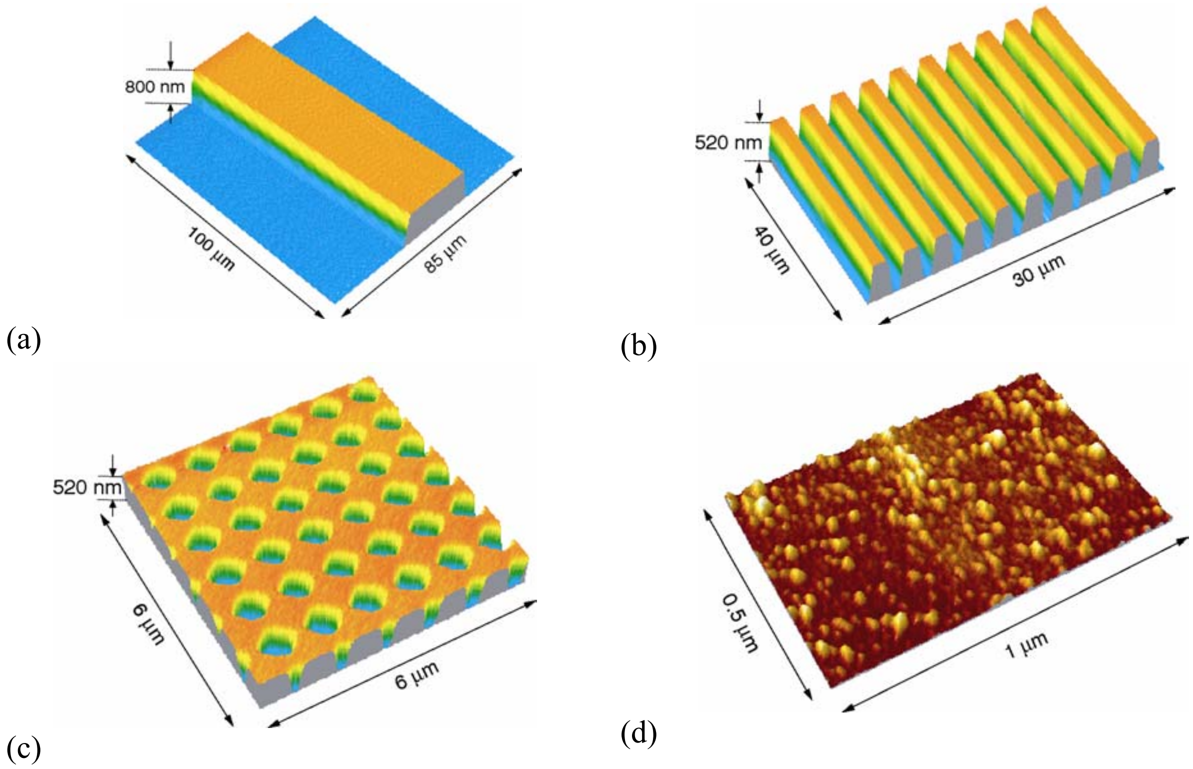


Fig.4. Photo of the new developed metrological stylus profilometer shown in (a). Its diamond tip observed in the CCD camera is shown in (b), and is compared to that of the SPM tip shown in (c) with the same video magnification.

The stylus detection head has the same mechanical and electronic interface as the existing SPM detection head of the LR-SPM. As the benefit, different detection techniques are exchangeable within 10~20 minutes in our instrument. The measurement software is compatible for both detection heads. The photo of the instrument is shown in Fig.4 (a). Its diamond tip observed in the CCD camera is shown in (b), and is compared to that of the SPM tip shown in (c) with the same video magnification.

SELECTED MEASUREMENT RESULTS

A number of extensive investigations, calibration services, PTB-internal and international comparisons have been carried out using the described metrological SPMs. Calibrations of flatness standards, one-dimensional and two-dimensional gratings, nano and micro roughness standards, nano and micro step height standards (or depth setting standards, film thickness standards), and so on have been successfully performed. As an example, some measurement results are shown in Fig.5.



(a) (b) (c) (d)

Fig.5. Some measurement results using metrological SPMs ((a) - step height standard; (b) - one-dimensional grating; (c) - two-dimensional grating; (d) - roughness standard).

References:

[1] G. Dai, F. Pohlenz, H.-U. Danzebrink, M. Xu, K. Hasche, G. Wilkening, Rev. Sci. Instrum. 75 (2004) 962.
[2] G. Dai, F. Pohlenz, H.-U. Danzebrink, K. Hasche, G. Wilkening, Meas. Sci. Technol. 15 (2004) 444.
[3] M. Bienias, S. Gao, K. Hasche, R. Seemann, K. Thiele, Appl. Phys. A 66 (1998) 837.

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