euspen's 16th International Conference & Exhibition, Nottingham, UK, May 2016

www.euspen.eu

Reference areal surface metrology by high speed metrological large range AFM

Gaoliang Dai, Andre Felgner, Ludger Koenders, Jens Fluegge

Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany

Email: Gaoliang.dai@ptb.de

Abstract

A new idea of reference areal surface metrology is presented. Unlike the conventional calibration procedures where a certain set of characterised parameters are usually focused, the reference areal surface metrology mentioned here is to provide accurate and traceable reference 3D data maps of surfaces. By correlating the reference 3D data sets and the 3D data sets of tools under calibration, it is potential to comprehensively characterise the tools, particularly its probe sample interaction and spectrum properties of tools. To meaningfully compare two data sets in the same spectrum window, they must be measured with the same measurement range and pixel density. A high speed metrological large range atomic force microscope (Met. LR-AFM) is developed, optimised and investigated for realising the proposed reference areal surface metrology. Finally its applications are demonstrated by calibrating several optical areal surface measurement tools.

Keywords: Areal surface metrology, reference metrology, high speed metrological large range AFM, calibration, probe sample interaction

1. Introduction

Today calibrations of areal surface measuring instruments are typically performed using a set of artefacts such as step height, grating, optical flats etc. for characterising the geometrical properties of the instruments (e.g. the scaling factors, linearities, squareness, flatness and noise [1-2]). Although being essential, these calibrations are still insufficient to fully characterise the measurement properties of the instruments, particularly the complicated probe sample interactions.

To overcome this challenging issue, a new idea of reference areal surface metrology is proposed in this paper. The reference metrology is to offer accurately and traceably calibrated reference 3D data maps of surfaces. By correlating the reference 3D data sets and the 3D data sets of tools under calibration, it is potential to comprehensively characterise the tools, for instance, its probe sample interaction and spectrum properties of tools.

2. High speed Met. LR-AFM for reference surface metrology

Atomic force microscopic (AFM) technique has outstanding metrology properties such as high lateral (defined by the tip geometry, down to a few nm) and high vertical (sub-nm and below) resolution, low measurement uncertainty, non-destructive and 3D measurement capability. These features make the AFM technique an ideal candidate for realising reference areal surface metrology.

Unfortunately, there are several critical limiting issues. Firstly, the scan range of a conventional AFM is small, typically tens of micrometres. Consequently, it leads to significant deviation between the AFM and optical results as shown in many previous studies [3], which is attributed to a nature limit namely that different tools measure in different spatial spectrum window. For realising reference surface metrology, the reference tool and the tool under calibration should be able to perform measurements with the same measurement range and the same pixel density, which can thus allow the correlation of the reference 3D data sets and the 3D data sets of tools in a meaningful way. Secondly, the scanning speed of AFMs is usually very low, typically tens of µm/s. It not only leads to a very low measurement throughput, but also suffers from remarkable measurement drift due to the long measurement time needed. Some high speed AFMs are available today [4], however, they are mainly applied in bioscience for dynamic visualization of nanostructures and their metrology performance is not concerned.

PTB has developed a Met. LR-AFM with a capable measurement volume of 25 mm x 25 mm x 5 mm (x, y and z) [5], is therefore highly potential for reference surface metrology. However, till now the low scanning speed of the Met. LR-AFM (typically <50 µm/s) is a practical barrier.

To overcome this challenging issue, recently we have improved the measurement speed of Met. LR-AFM by a factor of more than 20 [5], thus significantly enhanced its measurement throughput and reduced its measurement drift. Its measurement principle is shown in figure 1. Same as our previous Met. LR-AFM, the instrument is based on a large range mechanical stage referred to as a nanopositioning and nanomeasuring machine, NMM [6].

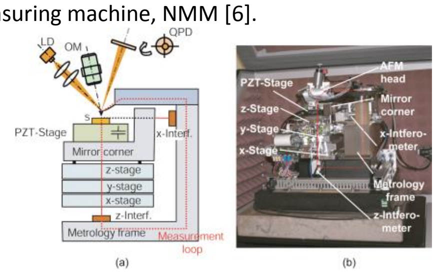

Figure 1. (a) Schematic diagram of the high-speed metrological large range AFM (High speed Met. LR-AFM); (b) photo of the instrument.

Several important design concepts have been implemented to realise both, high measurement speed and high metrology performance:

(1) the contact AFM mode is applied instead of the intermittent and non-contact modes, which offers shorter AFM response time and larger AFM sensing range.

(2) during measurements, the sample is scanned in the xy-plane solely by the NMM (such a motion usually has a constant velocity, therefore, high dynamics of the xy-

scanner is not needed.), however, a high dynamic z motion of the sample is realised by a combined piezo stage and the z-sage of the NMM controlled in parallel.

(3) the AFM output signal is combined with the position readouts of the piezo stage and the NMM to derive the surface topography. The combination of these readouts offers a large bandwidth of measurement signals, thus provides high speed measurement capability.

(4) two important means are taken to reduce the distortion in measured profiles, namely (a) the time delay of sensor signals are corrected; (b) the position sensors of the AFM and piezo stage are traceably calibrated to the z-interferometer of the NMM *in situ*.

To demonstrate the metrology performance of the high speed Met.LR-AFM, figure 2(a) shows a same surface profile measured at different speeds (from 10 µm/s up to 500 µm/s). It can be seen the quality of measured profile is very similar despite the scanning speed has been increased by 50 times. The excellent metrology performance of the device has been reported elsewhere [5,6].

AFM tip wear is a critical issue, particularly for high speed AFM. In this study, AFM tip type ContDLC (Nanosensor), whose tip is coated with a diamond like carbon (DLC) layer, has been applied for AFM measurements. The tip geometry is characterised by a tip characteriser (a kind of sharp silicon triangular nanostructure) before and after the measurements, as shown in figure 2(b), indicating very low tip wear.

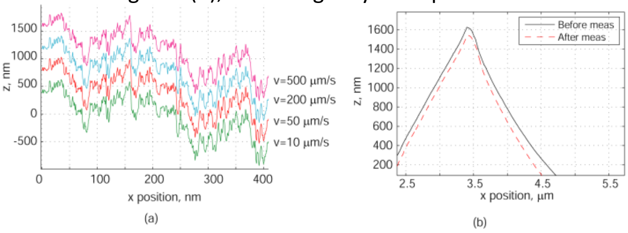

Figure 2. (a) Surface profiles taken on a PTB roughness standard (RN 505) by the high speed Met. LR-AFM, measured at the same location with different speeds from 10 µm/s up to 500 µm/s; (b) Tip shape characterised before and after measurements. Profiles are intentionally shifted along the y-axis for clarity.

3. Application example of the reference surface metrology

Several optical surface measurement tools including confocal, white light interference and phase shift interference microscopes are investigated using the developed reference surface metrology. Due to the limited paper length, just a part of results is presented here.

Figure 3 shows the investigation result of a commercial confocal microscope referred as tool A with a 50x objective (tool's name is kept as anonymous for commercial reasons). Both measurements are taken on a same PTB roughness standard (SN505, nominal *Ra* of 184 nm) with a same pixel density (193.3 nm/pixel) and area size (198 µm x 198 µm), thus allowing a direct comparison of two data sets in the same spectrum window. To account for the slight deviation of the measurement locations in two tools, the two data sets are aligned with each other using the cross-correlation algorithm. As the obtained areal surface topography images look quite similar, the comparison of a cross sectional profile of two data sets is illustrated in figure 3(a) with their discrepancies detailed in 3(b). It can be seen that the low frequency components of the surface in two data sets agree quite well, however, the optical results show significant artificial high frequency artefacts, especially in the valley and slope surface regions, which may be attributed to the optical probe sample interaction. In addition, a lateral shift of surface features (marked as A and B) is clearly visible at the left part of the image. It is probably due to the field distortion of the optical system, as the lateral scale of the microscope was properly calibrated prior to this investigation. Figure 3(c) shows the averaged power spectrum density (PSD) curves of the x-profiles of two data sets. Again, deviations for the components with frequencies > 0.2 1/µm are clearly visible.

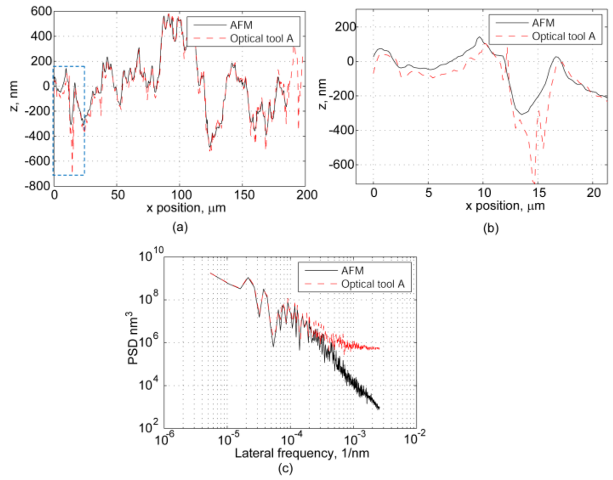

Figure 3. (a) comparison of a cross sectional profile of the measured reference data set and the data set measured by a commercial confocal microscope A; (b) detailed view of the discrepancies between profiles zoomed-in at the area marked in (a); (c) comparison of the averaged 1D power spectrum density (PSD) curve of two data sets.

Similar investigations have been performed on another commercial confocal microscope referred as tool B with a 50x objective, pixel density of 331 nm/pixel and field size of 254 µm x 190 µm. The measurement and data processing are the same as that of the previous study. Again, a cross sectional profile of two data sets is compared in figure 4(a) and the averaged PSD curves of x-profiles of two data sets compared in figure 4(b), showing surprisingly good agreement.

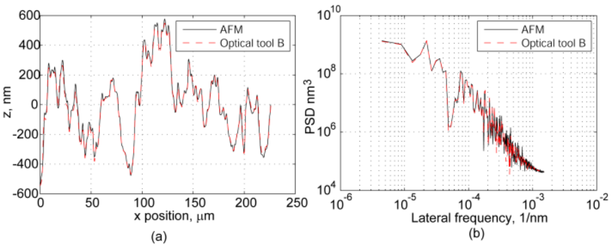

Figure 4. (a) comparison of a cross sectional profile of the measured reference data set and the data set measured by a commercial confocal microscope B; (c) comparison of the averaged 1D power spectrum density (PSD) curve of two data sets.

To summarise: a new idea of reference areal surface metrology, which is potential to comprehensively characterise the probe sample interaction and spectrum properties of areal surface measurement tools, has been presented. The realisation and application of the idea is detailed.

References

[1] Giusca C L, Leach R K, Helary F *et al.* 2012 *Meas. Sci. Technol.* **23** 035008

[2] Giusca C L, Leach R K, Helary F 2012 *Meas. Sci. Technol.* **23** 065005

[3] Poon C Y, Bhushan B. 1995 Wear ***190*** 76-88 II

[4] Ando T 2012 *Nanotechnology* **23** 062001

[5] Dai G, Wolff H, Pohlenz F *et al.* 2009 *Rev. Sci. Instrum.* **80**, 043702

[6] Dai G, Zhu F, Fluegge J 2015 *Meas. Sci. Technol.* **26** 095402

[7] Manske E *et al.* 2007 *Meas. Sci. Technol.* **18** 520