

Integrated optical profiler and AFM : a 3D metrology system for nanotechnology

M. Jobin^{1,2}, A. Du¹ and R. Foschia²

¹Geneva School of Engineering (EIG), University of Applied Sciences

4 rue de la Prairie, 1202 Genève, Switzerland, jobin@eig.unige.ch

²NanoFeel, 4 Tir-au-Canon, 1227 Carouge, Switzerland rfoschia@nanofeel.com

ABSTRACT

A white light interference optical profiler (WL-IOP) operating in the vertical scanning interferometry (VSI) mode has been home-made developed and integrated into a commercial Atomic Force Microscope (AFM). The result is a 3D metrological tool operating with sub-nanometer resolution vertically over a wide range laterally: from 1mm down to 10nm. This is a faster and in many case a higher performance alternative to the more standard stylus profiler / AFM combination.

Keywords: 3D Metrology, White-light interference Microscopy, Atomic Force Microscopy

1 INTRODUCTION

The ability to perform accurate metrology measurement at the nanometer scale is a requirement in many nanotechnology applications, particularly in semiconductors and MEMS industries. Common 3D metrology tools widely used in those industries includes stylus profilometry, optical profilometry and closed-loop atomic force microscopy (AFM). The later has the advantage of a very good resolution, both laterally (2nm) and vertically (0.1nm), which makes AFM the choice instrument for analyzing defects or structures at high resolution. A drawback of AFM is its speed of operation, in terms of analyzed sample surface per analysis time. In addition, the field of view per image is limited, usually 100µm or below. Therefore, it is natural to combine AFM with a larger field of view metrology system in order to first quickly localize the area of interest (e.g. defects) and then to measure it with AFM.

The most common choice along this line is to combine AFM with stylus profiler, probably because the two techniques compares easily (an AFM can be viewed as a high resolution mechanical profiler) and also because the mechanical integration is quite straightforward. However, the combination with optical profilometry might be a better solution in most applications, since it is non-contact (completely non-invasive) and faster compared to stylus profilometry.

White-light interference microscopy [1] (also referred to as low coherence microscopy) is a technique using an

interference objective, a white-light illumination and a piezoelectric positioning mechanism allowing to modify the sample /objective distance with nanometer accuracy. The technique has a vertical range in principle unlimited (in practice it is limited by the vertical scanning stage on which the objective or the sample is mounted) and a sub-nanometer resolution in the vertical axis.

2 EXPERIMENTAL SETUP

2.1 Mechanical and Optical setup

We chose to design our own white light interference profiler and to integrate it into a commercial AFM [2]. The general set-up of the instrument is shown in Fig 1.

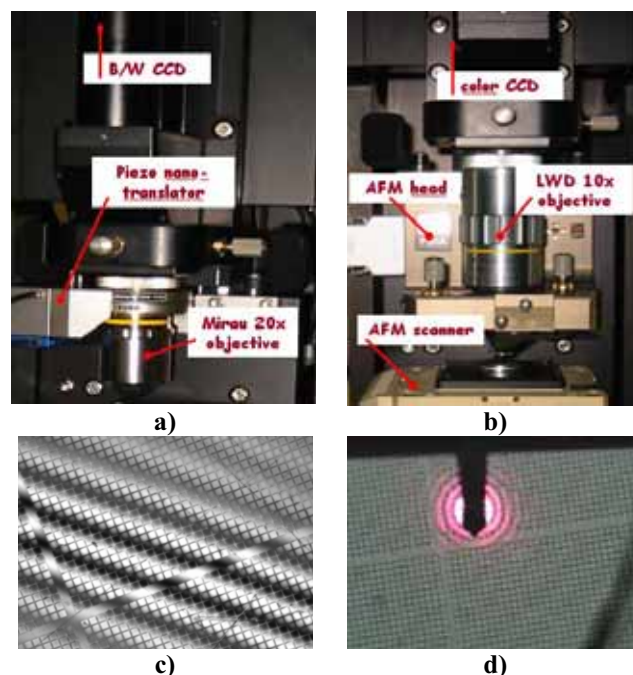


Figure 1: Setup of the instrument in a) WL-IOP mode b) AFM mode, with the corresponding optical images in c) and d).

To switch from optical profilometry (WL-IOP) to AFM, both the AFM head and the microscope objective are slide laterally. Mirau-type interferometric objectives (10x, 20x and 50x) are used in WL-IOP mode and a long working distance 10x objective in AFM mode. The white-light

illumination system (standard halogen bulb) is used for both modes. The interferometric objective is mounted on a closed-loop piezoelectric translator with 1nm resolution and 200μm range.

A two-axis tilt stage (+/- 2°) is mounted in between the AFM scanner and the mechanical XY positioning stage. Due to the thickness of the scanner, the sample is not in a perfect gimbal configuration. However, this gives only minor annoyance for the alignment.

2.2 Reconstruction Algorithm

A typical WL-IOP acquisition consists of recording images 20nm apart over the whole range of focus of the specimen under inspection. Our setup allows CCD frame acquisition at a rate of 30 fps, which corresponds to an acquisition time of 1.6 sec per micron of sample corrugation.

The optical intensity at a given pixel (x,y) as a function of the z position (i.e optical path difference) is called a correlogram. Due to the slight tilt given to the sample relative to the Mirau objective, the interference fringes as seen on Fig 1b) will slowly move across the image as the objective is scanned vertically. The correlogram $I_{xy}(z)/T$ has a maximum modulation at zero optical path difference (OPD), corresponding approximately to the focus point.

A typical untreated correlogram $I_{xy}(z)$ is shown in Fig 2a). It has the expected features for a low coherence interference signal, i.e fringes are localized over a short distance around the zero OPD.

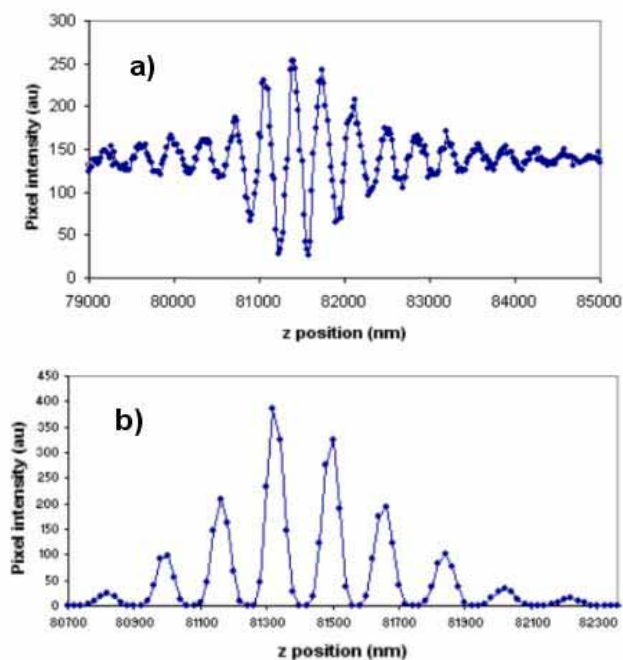


Figure 2 : a) untreated correlogram, b) processed correlogram for peak detection

To reconstruct the true z-position from the correlogram on each pixel, an algorithm has to be used to detect the peak position of the envelope of the correlogram. Many algorithms have been proposed for this purpose [3] [4] [5]. In our case, an important criterion for the algorithm is the computational time as we want to use the WL-IOP as a fast defects detection tool before AFM investigation.

We developed our own algorithm which mix Fourier transform and centroid calculation. The processed correlogram used for the final determination of the zero OPD is shown in Fig 2b). Each correlogram take an average of 0.29 ms to reconstruct. For an actual 640 x 480 image reconstruction (which is standard, but we also used a 1024 x 784 CCD occasionally), this corresponds to 90 seconds reconstruction time.

The actual calculated profile on a mirror (commercial grade) is shown in Fig 3. Sub-nanometer resolution is clearly achieved and the groove indicated by the arrow is 1.4 nm deep.

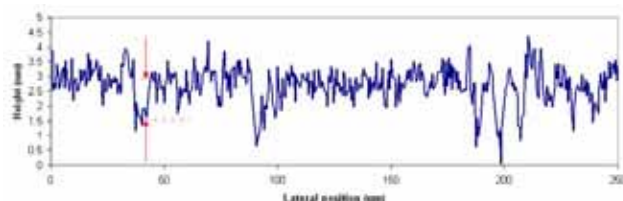


Figure 3 : Cross section of a polished mirror in the WL-IOP mode

3 RESULTS AND PERFORMANCES

Fig 3 is an example of the integrated WL-IOP/AFM operation. The sample we used was a standard calibration grating (pitch 9.9μm) made of silicon. No significant oxide thickness variation is expected for this sample, excluding then multiple interference artifacts [6] in white-light interferometry.

The optical interference profiler is used at first to image a large field of view (FOV) of the sample. Fig 4a) is a 3D reconstruction view [7] of the WL-IOP data for a field of view of 350μm x 270 μm. Many defects can be seen on this reconstruction, defects that cannot be detected with standard bright field microscopy, for example grooves, pinholes and small dust particles. For a careful inspection of the surface, we found often advantageous to digitally zoom into the surface, as shown in Fig 4b). At this stage, we choose the area to be scanned with the AFM, represented in Fig 4b with a white square. An example of cross section analysis on the WL-IOP is shown in Fig 4c). The coordinate of the area of interest (AOI) is recorded and transferred to the AFM in order for the AFM probe to be directly positioned correctly when the system will be switched to AFM mode. Fig 4d) shows a high resolution AFM image over the AOI.

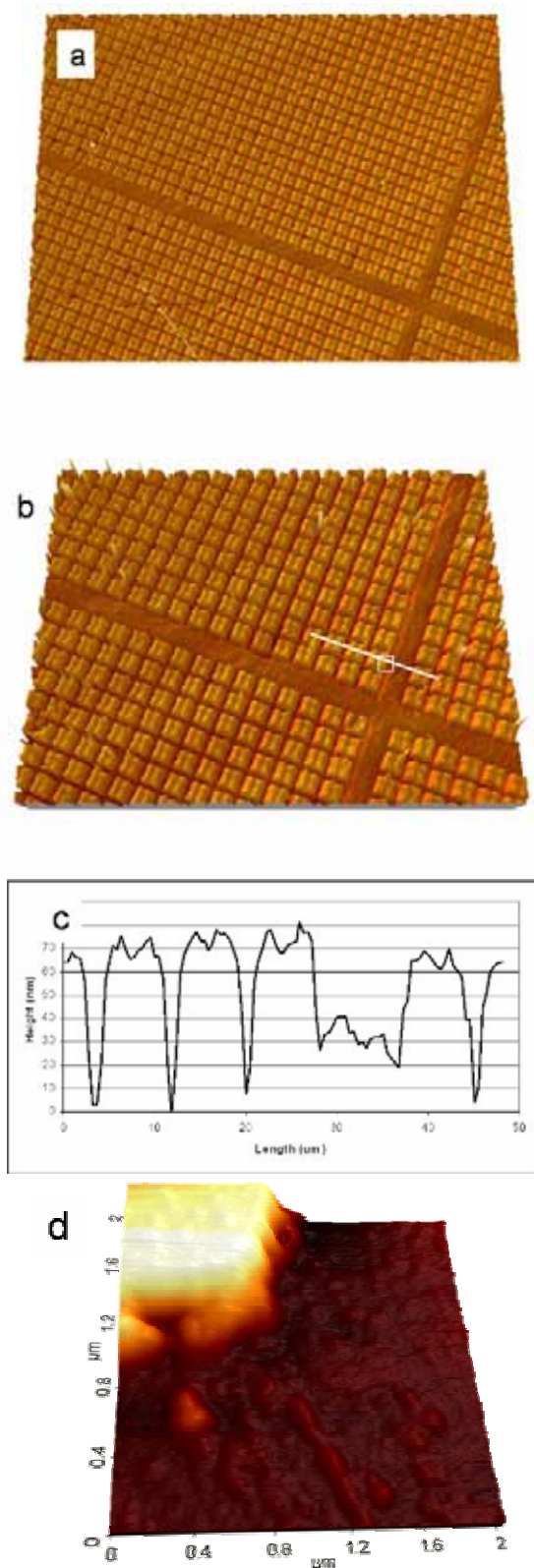


Fig 4 : Example of integrated WL-IOP /AFM operation.
a) Large field of view (350um x 270um) WL-IOP image in 3D view
b) Digital zooming and cross section selection of the area of interest
c) Cross section in the W: -IOP mode
d) AFM image (2um x 2um) over the selected area in b).

4 CONCLUSIONS

Our combined white-light interference optical profiler (WL-IOP) and AFM provides a fast, reliable and efficient 3D metrology system operable from 10nm to 1mm laterally with sub-nanometer vertical resolution over the whole lateral range. Such a combination should be particularly useful for quality control application in MEMS industry.

Further development of our system includes the phase-shift interferometry (PSI) mode and improved reconstruction algorithms for batwings effects [8] cancellation.

REFERENCES

- [1] See for example: P.J. Caber, *Appl. Opt.* **32**, 3438 (1993)
- [2] Model XE-100 from PSIA, Seoul, Korea (www.psia.co.kr). We also integrate it to a Nano-R from Pacific Nanotechnology, Santa Clara, CA (www.pacificnanotech.com)
- [3] L. Deck and P. de Groot, *Appl. Opt.*, **33**, 7334 (1994)
- [4] G.G Larkin, *J. Opt. Soc. Am.*, **13**, 832 (1996)
- [5] P. Sandoz, *Opt. Lett.*, **22**, 1065 (1997)
- [6] M. Roy, I. Cooper, P. Moore, C. Sheppard and P. Hariaran, *Optics Express*, **13**, 164 (2005)
- [7] we used SPIP software from ImageMetrology, Copenhagen, Denmark (www.imagemet.com)
- [8] A. Harasaki and J.C Wyant, *Appl. Opt.*, **13**, 2101 (2000)