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Measurement platform with a multi-functional MEMS-SPM head for high-throughput characterisation of nanostructured materials

Christian Kuhlmann[1], Zhi Li[1], Ole Willke[1], Radovan Papadic[1], Uwe Brand[1]

[1] *Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig, Germany*

christian.kuhlmann@ptb.de

Abstract
For the investigation of micro- and nanostructured materials, such as vertically aligned nanowires for energy harvesting, an innovative microelectromechanical system (MEMS) based scanning probe microscope (MEMS-SPM) head has been developed, allowing nanodimensional and nanoelectromechanical characterisation of such samples. This MEMS-SPM head uses comb-drive structures for in-plane displacement and force sensing, achieving a displacement resolution down to 100 pm and a force sensitivity in the nN range, respectively. Owing to its integrated AFM cantilever gripper, the MEMS-SPM head can be equipped with various commercially available AFM probes. This MEMS-SPM head has been integrated into a recently developed high-speed nanodimensional and nanoelectromechanical measurement platform (HSNNP). To demonstrate the fundamental performance of this multi-functional measurement system, first measurement results of typical reference artefacts and typical samples, such as nanopillars, are reported in this manuscript. Further development details of the measurement system, including its roadmap, are also outlined.

Surface metrology, semiconductor nanowires, MEMS, scanning probe microscope, nanomechanical measurements

1. Intoduction

Microelectromechanical system (MEMS) based force-displacement sensors have shown promising results with respect to achievable noise and resolution [1]. Their high lateral stiffness in combination with an integrated cantilever gripper make them very suitable for nanomechanical experiments with a wide selection of tip types to choose from. The option to use conductive tips allows through-tip electrical measurements, which are crucial for the investigation e.g. of piezoelectric nanowires under well defined uniaxial force application [2]. A measurement head featuring such a MEMS has recently been integrated into a modular measurement platform to carry out a variety of scanning probe microscopy (SPM) tasks.

2. System setup

The mechanical system is built based on a commercially used coarse positioning system (HM2000, Helmut Fischer GmbH Institut für Elektronik und Messtechnik, Germany) consisting of a granite base carrying linear stages for the x- and y-axes and a granite column, on which the z stage is mounted. A large positioning range of 300 mm × 150 mm × 100 mm allows to position the sample either under the measurement head or under an inspection microscope. Fig. 1 shows a photograph of the system together with a schematic representation.

Atop the coarse y-stage, a three-axis piezo stage with a positioning range of 75 µm × 75 µm × 50 µm (Nano-LPQ, Mad City Labs Inc., USA) is mounted, carrying the sample holder and moving the sample for fine positioning and scanning operations. It has a high maximum positioning speed of 22 mm/s and can sample its position at up to 30 kHz.

The MEMS-SPM measurement head is mounted on the z coarse stage and is fixed during scans. An additional microscope directed at the MEMS-SPM tip allows observation of the sample during sample engagement and scans. Custom built electronics based on AD7746 (Analog Devices Inc., USA) integrated into the measurement head acquires the tip displacement of the MEMS.

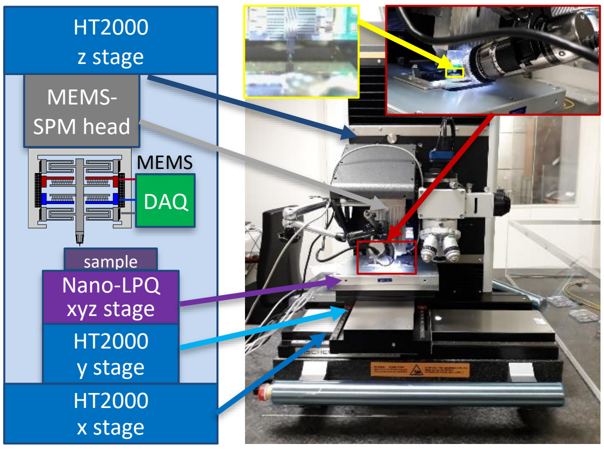

Figure 1. Photograph of the whole system (right) along with a schematic representation (left). The top right inset shows the sample area, the inset at the top left shows the image obtained by the front microscope.

3. Control software

Since the system is intended for high-throughput measurements, fast acquisition of sampled data is a central requirement for the control software. Additionally, it should be modular, so that component upgrades or additions can be easily incorporated. Its modules represent hardware functionality, hiding the peculiarities of individual APIs by providing a common interface for each device type, while performing their tasks in parallel. Each module follows the actor abstraction and functions as autonomously as possible, with only software triggering, file management and command message passing as connection points to other modules (c.f. Fig. 2). To achieve further automation and enable self-documenting measurements, a Python-interface allows the user to script and document tasks via measurement recipes.

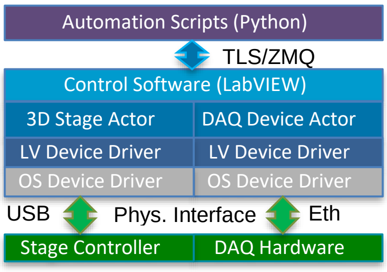

Figure 2. Control software architecture. Modules are based on the actor abstraction model and represent generalized hardware devices.

4. Basic performance parameters

To reduce the magnitude of resonances excited in the sample and the system, a 4th order polynomial based movement profile has been implemented. Fig. 3 shows that the system is able to reasonably reproduce this profile for scan speeds up to 1 mm/s.

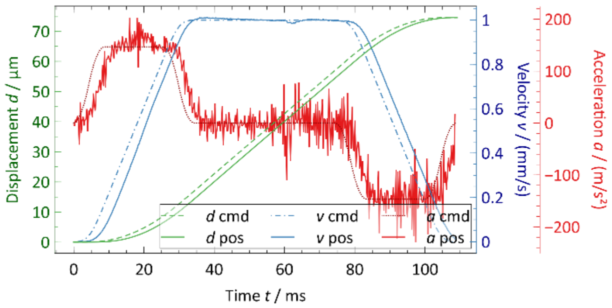

Figure 3. Measured position, velocity, acceleration profile compared to the commanded waveform (dashed).

Additionally, the noise in the vertical axis of the system has been investigated by making contact to the surface of a silicon wafer. Fig. 4 depicts the obtained noise spectrum of one hour of data acquisition. While the white noise floor is reasonably low, we intend to improve upon the $1/f$ noise region by adding an instrument housing and by compensating z-axis drift.

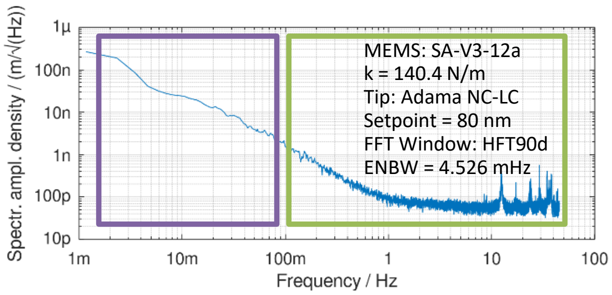

Figure 4. System z-axis noise spectrum, parameters as shown.

5. Areal scans

In order to verify the basic scan functionality, images of a grating structure with pitch and depth of 10 µm × 10 µm × 180 nm (VGRP-15M Bruker) have been acquired at v=6 µm/s. Fig. 5 shows the results as obtained by the system without further corrections or postprocessing. Synchronization between stage movement and data acquisition works well, while inter-line-differences reveal slight short-term drift in the z-axis that needs to be further investigated and handled.

To test the system with more challenging topographies, scans of nano-pillars made from silicon (111) with 0.8 µm diameter and (4 µm, 5.8 µm) (x, y)-pitch and 500 nm height (S05, TU-Braunschweig, [3]) have been performed. Due to the uniaxial sensitivity of the MEMS, the resulting lateral tip forces of rounded topographies present a more challenging artifact.

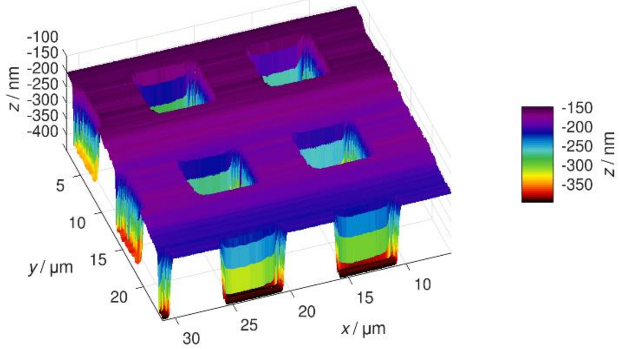

Figure 5. Image obtained from a scan of a VGRP-15M grating structure.

Fig. 6 depicts the resultant image at v=0.5 µm/s, again without any postprocessing. The pillar can be clearly identified and is well reproduced. The visible non-circularity of the pillar base is mainly due to the convolution with the tip-shape.

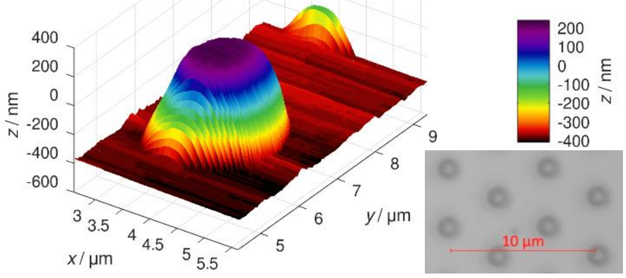

Figure 6. Scan and optical image (right) of 0.8 µm × 500 nm nano-pillars.

6. Conclusion and future work

We have presented a modular high-speed nanodimensional and nanomechanical measurement platform and demonstrated its basic hardware and software functionality by showing first topographic areal scans.

Future improvements to the system will include the incorporation of electrical measurement capabilities, as well as compensation of z-axis drift. Upgrades to the data acquisition hardware will allow increased scan speeds while maintaining current image resolution. Additionally, the control software will be extended to allow nano-electromechanical measurements, such as modulus mapping.

Acknowledgements

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