Six - axes AFM in SEM with self-sensing and self-transduced cantilever for high speed analysis and nano-lithography

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Atomic Force Microscopy (AFM) and Scanning Electron Microscopy (SEM) are routinely used techniques for high-resolution surface research.

The self-sensing and self-transduced cantilever [1-3] allows an easier system integration and substantial decrease of the mass of the scanning head. The AFM microscope provides better controllability, significant higher imaging speeds with the potential for CD-metrology automation, and an in-situ inspection capability combined with the SEM.

In this paper, the concept and first results of novel AFM in SEM for nanoscale characterization are presented. A six-axes AFM system is being developed and integrated into a high resolution SEM/FIB system allowing nanoscale analysis, nano-manipulation and scanning probe lithography. The compact and modular AFM setup enables probe- as well as sample-scanning and uses self-sensing AFM cantilevers. The top-probe-scanner allows positioning of the cantilever in a space pf 20mm x 20mm x 10mm with precision of 1nm. The sample-scanner is used for metrology purposes securing 0.2nm resolution in x-, and y-axes and 0.1nm in z-axes. Simultaneous control imaging software was developed to merge SEM and AFM information for mixed imaging of nanoscale objects. A FPGA AFM controller is embedded into a special control system architecture that allows for automation of nano-manipulation imaging and SPL-sequences. The operation modes of the AFM include contact, non-contact, mass-detection and scanning-probe lithography [4]. The controller is offering amplitude-, frequency-, and phase-sensitive detection.

With respect to resolution and robustness, this technique is directly dependent on tip quality (material, aspect ratio, shape and operation mode of the AFM). Therefore, a carefully calibration of CD-AFM includes a probe geometry deconvolution and can be used as metrological tool where a key parameter is the shape of the tip. The active cantilever includes a conical shaped tip with 15 +/-3 nm radius which is formed in highly doped, single crystal silicon, and offers long life in non-contact operation and is favorable for top-CD measurement of lithographical features and long-life operation as Fowler-Nordheim emitter for Scanning Probe Lithography [5].

These work goals at providing a new eloquent representation of detailed results from combined examinations, by applying fast AFM-methods and SEM-image fusion, AFM-SEM combined metrology verification and 3D-visualization. Combined AFM and SEM capabilities provide a view of sample topography due to a large number of hybrid imaging and sub-10nm measurement techniques. Metrology application scenarios from a combined AFM and SEM study will be discussed.

Acknowledgments
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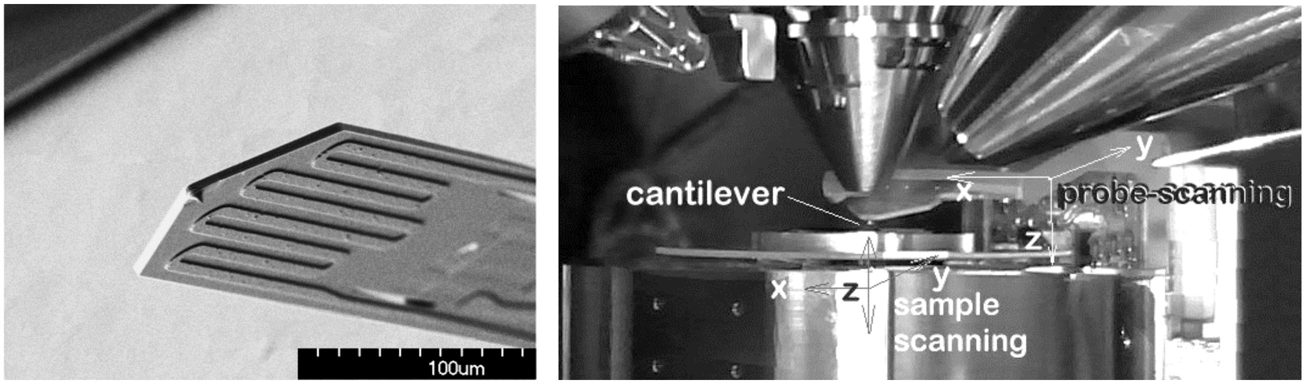
[1] I. W. Rangelow, S. Skocki, and P. Dumania, "Plasma etching for micromechanical sensor applications" Microelectron. Eng. 23, 365 (1994).
[2] I.W. Rangelow, "Scanning proximity probes for nanoscience and nanofabrication," Microelectron. Eng. 83,1449–1455 (2006). [3] M. Kästner et al., "Scanning probes in nanostructure fabrication" JVSTB B 32, 06F101 (2014); doi: 10.1116/1.4897500
[3] A. Ahmad, Tzv. Ivanov, T. Angelov and I.W. Rangelow, Fast atomic force microscopy with self-transduced, self-sensing cantilever, Journal of Micro/Nanolith. MEMS MOEMS 14(3) 031209 (Jul-Sep 2015)
[4] M. Kästner et al., "Scanning probes in nanostructure fabrication" JVSTB B 32, 06F101 (2014); doi: 10.1116/1.4897500
[5] M. Kästner et al., Journal of Micro/Nanolith. MEMS and MOEMS Vol. 14(3), 031202 (Jul-Sep 2015)



a) b)

Figure 1. (a) Self-sensing and self-transduced cantilever used for AFM in SEM; (b) Picture of the SEM-CCD-camera shows the AFM in SEM set-up. The design allows probe- as well as sample-scanning, AFM tilting from -10° to + 60° and the SEM working distance of 4mm (high resolution).

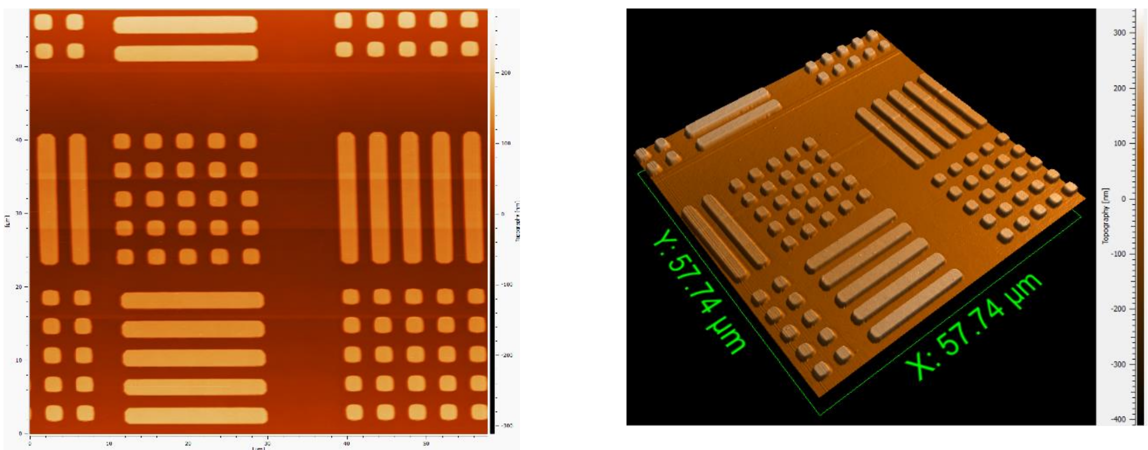
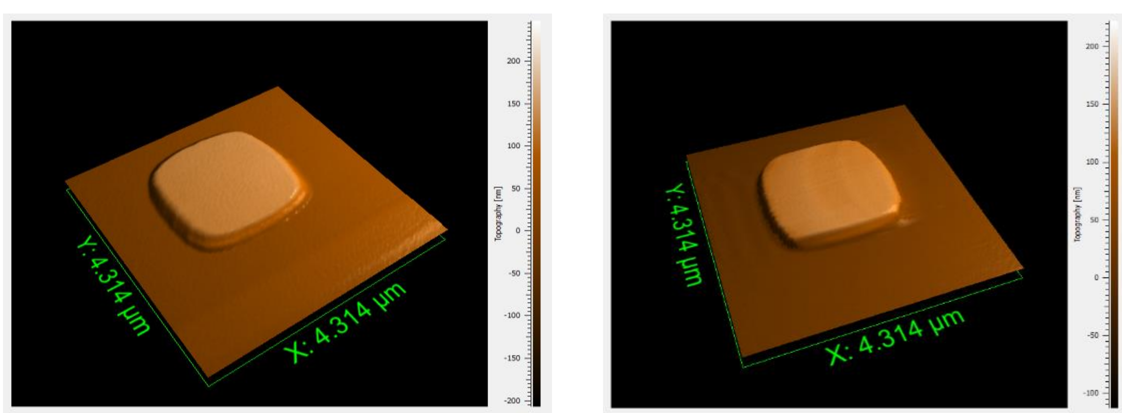


Figure 2. 2D and 3D AFM images obtained with the AFM in SEM.



a) b)

Figure 3. 3D AFM images obtained with the AFM in SEM, (a) 4 lines/sec (b) 50 lines/sec.