The SEM/FIB Workbench: Nanorobotics System Inside of Scanning Electron or Focussed Ion Beam Microscopes

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Abstract

A good part of the understanding about material functions and process technologies was developed by handling and preparing materials under light microscopes. But material properties and functionalities also depend on structure dimensions that are smaller than the wavelength of light. Material processing and assembly also ends up at this artificial boundary:

At light microscopes it is natural for every expert to use tool sets like tweezers, knives, hooks, probes and several different measurement tools. Without such handling, manipulation and manufacturing tools many present-day products and methods would not exist: No eye surgery, no wristwatch, no in vitro fertilization, just to mention a few. The operators of SEM, FIB or Dual Beam systems generally work without tool sets and call it natural, although the wavelength limit of light is no physical boundary for using such tools. It can be imagined how technology would be pushed when the in-situ SEM/FIB Nanorobotics reach the same degree of usage as tool sets at light microscopes.

The SEM/FIB Workbench developed by Klocke Nanotechnik[1] offers for the first time a secure and easy to use system for in-situ Nanomanipulation, object handling, material preparation, patterning & processing, micro/nano- manufacturing & assembly together with new methods for characterization and nano metrology. It can be integrated into most existing Scanning Electron Microscopes (SEM) and Focused Ion Beam (FIB), or Dual Beams (SEM/FIB) systems.

1 Development Challenges:

In general the success of in-SEM/FIB Nanorobotics depends on the combination of several important features in one global system. The main development challenges for such a new system were:

- A new series of absolute positioning Nanomanipulators including automation, for the securely guided movement of endeffectors or sample handling,
- Plenty of application sets for nano-probing, nano-cutting, force distance or wear measurements, sample preparation & processing or gripping, sorting & assembly,
- A new in-situ tip cleaning process, e.g. for continuous nano-manipulation or nano-cutting, avoiding unacceptable downtimes by locking out the tip,
- A new in-situ 3D-topography measurement module operating as Scout for sample and tool position detections, sample topography and roughness measurements,
- A modular design for fast configuring of nano-analytical, nano-processing or nano-handling and assembly processes, with self learning initializations,
- Automatic precise detection of all tool positions including SEM/FIB sample stage positions in global coordinates,
- A new SEM picture assisted manipulation by “Live Image Positioning”,

The upper developed items allowed the development of assistants and automation modules for Nanorobotics and SEM/FIB in one common control unit for secure and easy usage. Only this new level of common control enables the usage as one application system: it is not a pure SEM/FIB and it is not a pure Nanomanipulator, it is an application oriented machine with a secure and easy to use application control – like a person working at a light microscope together with tools in his hands operates as one unit forming an application.

2 Results and Applications:

This worldwide new SEM/FIB Workbench enables new interdisciplinary research and development fields, including material & forensic research, nano-biology & bionics, pharmacy, pathology, tribology, geology and semiconductor technology.

Several examples will be described during the presentation as review about already realized applications. Some examples thereof are highlighted now in FIG 1:

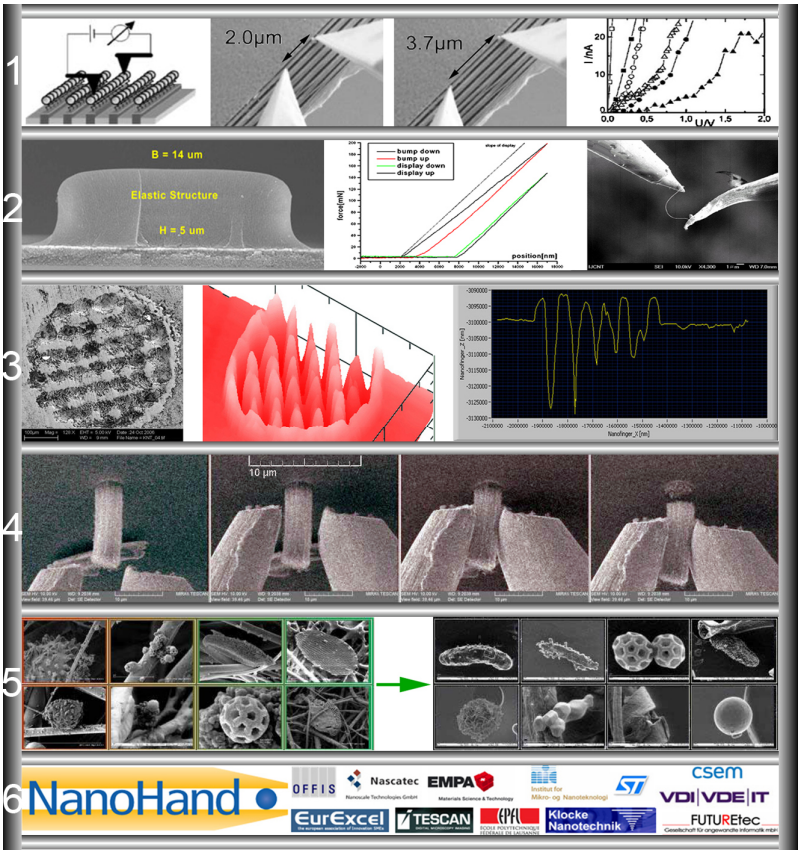

Figure 1: A brief summary of applications realized with the SEM/FIB Workbench. These rows include:

1) Nano-Probing of Gold55-Clusters arranged in chains [2]: The electrical conductivity along these gold chains is measured over different distances and compared with the conductivity of bare gold wires.

2) Nano-tribology and similar measurements can be performed in high resolution (friction, reliability, current and heat load, elasticity, wear …). One example is to measure the elasticity during bending a leg of a fly above its top joint with a force distance curve. This is only possible with the developed absolute positioning Nanomanipulators and a new developed special force sensor fitting into the small gap between electron source and sample.

3) The left SEM image is measured by the new "Dimensional SEM" module quantitatively, middle image as 3D-Topography, right image by scaled line scans. In addition roughness and dimensions can be measured [3].

4) Gripping of a rigid CNT bundle and separation from the ground. This process needs by orders more force then a microgripper normally can apply. For smaller structures other grippers are available, partly also with force feedback.

5) Particle sorting from source area (left image set) to clean target area (right image set) is a general application, needed in many different disciplines: from environmental research over crystallography up to forensic research. The SEM/FIB Workbench brings this complex handling process for the first time on a secure level with a high throughput enabling also industrial sorting applications.

6) The first parts of the SEM/FIB workbench were developed in the European Research project "NanoHand" [4], in particular the "NanoFab", a module that includes automatic handling systems with in total up to 18 degrees of freedom.

Conclusions:

The SEM/FIB Workbench developed and described above is an application oriented Machine, fully automated and integrated with a secure and easy to use application Control. It offers for the first time a secure and easy to use system for in-situ Nanomanipulation - object handling, material preparation, patterning & processing, micro/nano- manufacturing & assembly, together with new methods for characterization and nano metrology. It is a step forward towards managing complex handling processes and a high throughput, enabling also industrial applications.

References:

[1] Klocke Nanotechnik GmbH, www.nanomotor.de

[2] G. Schmid, M. Noyong, Generation and electrical contacting of gold quantum dots, (2008) Colloid Polym Sci., DOI 10.1007/s00396-008-1866-2

[3] Nanofinger, www.3D-Nanofinger.com

[4] NanoHand Project www.nanohand.org