Publishable Summary

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NanoWorld Services, JPK Instruments

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Participant no.	Participant organisation name	Participant short name	Country
1 (CO)	OFFIS e.V. -- Institute for Information Technology	OFFIS	Germany
2	Nanointegration Group, DTU Nanotech, Copenhagen, Denmark	DTU	Denmark
3	Swiss Federal Laboratories for Materials Testing and Research, Thun, Switzerland	EMPA	Switzerland
4	Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung e.V.	Fraunhofer	Germany
5	Nanoworld, Erlangen, Germany	Nanoworld	Germany
6	JPK Instruments, Berlin, Germany	JPK	Germany

Objectives

The atomic force microscope (AFM) has become a standard and wide spread instrument for characterizing nanoscale devices and can be found in most of today's research and development areas. The NanoBits project provides exchangeable and customizable scanning probe tips that can be attached to standard AFM cantilevers offering an unprecedented freedom in adapting the shape and size of the tips to the surface topology of the specific application. NanoBits themselves are 2-4 µm long and 120-150 nm thin flakes of heterogeneous materials fabricated in different approaches. These novel tips will allow for characterizing three dimensional high-aspect ratio and sidewall structures of critical dimensions such as nanooptical photonic components and semiconductor architectures which is a bottle-neck in reaching more efficient manufacturing techniques. It is thus an enabling approach for almost all future nanoscale applications.

A miniaturized robotic microsystem combining innovative nanosensors and actuators will be used to explore new strategies of micro-nano-integration in order to realize a quick exchange of NanoBits. For the fabrication of the NanoBits, two different techniques are proposed. On the one hand, a standard silicon processing technique enables batch fabrication of various NanoBits designs defined by electron beam lithography. On the other hand, focused ion beam milling can be used to structure a blank of heterogeneous materials, the so-called membranes. Novel scanning modes in atomic force microscopy will be developed to take full advantage of the different NanoBits geometries and to realize AFM imaging of critical dimension structures. The innovative nanoimaging capabilities will be applied to characterize and develop novel nanooptical photonic structures in the wavelength or even sub-wavelength range and TERS applications in the nanomaterial and biomedical sector. Especially the involved SMEs will exploit and disseminate the results to potential users to realize a more efficient micro-and nanomanufacturing.

Main results in 3rd reporting period

WP 1

- NanoBit plateau cantilevers with the defined specifications have been fabricated successfully

WP 2

- Process of poly-Si NanoBits fabrication using EBL was developed and the new batch of NanoBits of various shapes was manufactured.
- NanoBits of unified geometry in large arrays were successfully used for development of automated assembly.
- Various sharpening methods were considered and tested for NanoBit tips, showing tip radii down to 5 nm.
- Dependency of OOP bending degree relating to fabrication parameters was studied considering different models. A consistent empirical agreement was obtained.
- Physical-experimental conditions underlying the stress formation mechanism were studied for bilayer membranes and for FIB-exposed thin membranes.
- Smart FIB milling procedures were enhanced for HAR NanoBits achieving record AR=55 and uniformity of apex was improved (in lateral and membrane-thickness dimensions).
- A new set of FIB-fabricated NanoBits was prepared in sc-Si and poly-Si, followed by assembly and AFM testing.
- AFM scanning on several types of microscopes was carried out and scanning parameters were analyzed. NanoBit functionality was demonstrated with all AFM systems. Characterization of NanoBit tips was done regularly by OM, SEM, and at an advanced level by TEM and EDX.
- Dissemination of results was fulfilled in 2 scientific articles, accepted to peer-reviewed journals. 1 manuscript is in preparation.

WP 3

- A successful automation of an assembly process on the microscale has been demonstrated: the automated nanorobotic assembly of NanoBit’s cartridges inside the SEM is possible. The actual process time is about 1 minute per piece, but still possible to decrease.
- The hard- and software design is application proven and guarantees a fast development, even for upcoming tasks.

- The success rates of all steps differ and are consecutively depending on each other:
  - The gripping only works, if the intended breaking point well fabricated. If it is too strong, additional wiggle movements are necessary in order to weaken this point.
    - The success of the gripping itself can be nearly 100%.
    - A well aligned gripping of the NanoBit is (depending on the breaking point) between 50-90%.
  - A NanoBit can be gripped well aligned only, if the intended breaking point was weak enough, in such a way as no additional movements (like wiggling) are necessary.
  - The success of the insertion depends strongly on the correct detection of the NanoBits tip.
  - The well aligned and deep insertion depends again on a correct orientation of the NanoBit in the gripper.
- In summary, the intended breaking point reveals to be a critical component for the entire assembly process. The overall success rate depends more on the involved components than on the strategy itself.
- Experiments to grasp NanoBits without turning them showed that even more mechanical stress is necessary to break this point. This corresponds also to experiments with out-of-plane NanoBits, which are hardly breakable without turning movement (compare D2.3). Hence, the turn movement is still a reasonable approach.
- In general, the automated assembly of NanoBits into cartridges is possible but strongly depends on precisely fabricated components. The most crucial process step, the in-gripper turn of the NanoBit, is necessary in order to avoid large additional mechanical stress and resulting misalignments; hence well fabricated intended breaking point are essential.
- The required turn movement could be achieved by an additional rotatory degree of freedom of the gripper itself; but is not possible with any actual technological approach.

WP 4

- Scanning in lateral contact mode was validated experimentally and limitations of the approach were analyzed.
- Scanning algorithm for AFM-based 3D-scanning was developed and validated in simulations.
- A novel AFM mode based on torsional resonance (Intermittent lateral contact mode) was developed and validated experimentally.
- Experiments were conducted with different scanning szenarios were the scanning plane was switched automatically to gain 3D topological information of trench/sidewall structures.

WP 5

task 5.2:

- All the scans were performed in contact AFM mode hence, a strong mechanical influence is apparent.
- NanoBits show an anisotropic behavior, depending on the scanning orientation. This is a result of the different geometric conditions of the NanoBit itself.
- The longitudinal scanning direction does not exhaust the NanoBit-cantilever connection significantly. In contrary, the transversal scanning orientation weakens the NanoBit-cantilever connection tremendously.

task 5.3:

- Long-term tests:
  All the tested Nanobit probes except one were very stable and did not fail during the test procedure. The reason for the failure of the broken Nanobit was most probably (see section 2.3) due to the inadequate insertion depth of the Nanobit connector into the FIB-milled slit of the connector platform (plateau tip). All other tested Nanobit probes (with deeper inserted connector) did not fail this way.
- Evaluation for TERS:
  - The strong adhesion of NanoBits to the commercial tip allows scanning several times in non-contact mode.
  - The silver deposition on the NanoBits is not stable over the time and the scans (oxidation, delamination).
  - Spatial resolution expected in TERS spectroscopy ~ 250 nm.

WP 6

- A new kind of multilevel broadband blazed grating in resonance domain has been designed and fabricated. The grating is a combination of a three-level structure with a sub-wavelength feature on the bottom level. A new technological approach has been developed. This structure could be the perfect candidate to test the performances of HAR NanoBits.

WP 7

- TERS enhancement is successfully demonstrated with the new device
- TERS enhancement is successfully demonstrated with NanoBits-functionnalized tips TERS
- Enhancement of a factor 5-6
- Diameter of the hotspot below the tip ~ 800 nm
- Due to surface state of the silver coating, the spatial resolution is < 300nm

WP 8

- Public NanoBits workshop at the Transducers 2013 in Barcelona, Spain.
- Publications in scientific journals and conference contributions.
- Updated plan for Use and Dissemination
- Dedicated plan for commercialization of a 3D-AFM measurement system

WP 9

- The NanoBits 2nd review meeting was organized in Brussels
- 4th Technical Meeting was organized in Hamburg
- NanoBits Workshop was planned in Barcelona
- Final reporting was prepared and composed
- Final Meeting was organized in Oldenburg
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Expected impact

The developments in the NanoBits project are anchored in the field of nanotechnology, which has become an interdisciplinary key and enabling technology. Nowadays, in the technology driving fields of semiconductor technology, nanoelectronics, photonics and life sciences as well as in other smaller disciplines almost everything is “nanoscale” since the sizes of circuitry in computers CPUs, nanoelectronics, optical structures and molecular structures are such. Progress in these fields of technology research is strongly driven by high-tech nanotechnological developments such as the development of the atomic force microscopy (AFM). Especially in the field of AFM-based characterization of such nanostructured devices, there is up to now a lack of tools that allow for a full characterization of 3D nanodevices having critical dimensions such as high-aspect ratio, sidewall, and even overhanging structure but that are needed to advance the aforementioned fields of science. The NanoBits project provides a technique to characterize such nanostructures and thus to enhance the quality and efficiency of today's micro- and nanomanufacturing processes. The NanoBits project intends to impact on a large number of industries utilizing nanotechnology by advancing the nanodevices characterization, synthesis, and their related manufacturing processes in the field of semiconductor technology, nanoelectronics, photonics and life sciences as well as in other smaller disciplines. The major impact of the NanoBits project will be that the consortium, two SMEs, assisted by the knowledge and expertise of the participating RTD institutes, will be able to realize and commercialize a unique, 3D AFM-based characterization tool for nanotechnology.

In summary, the NanoBits project will offer novel customizable and exchangeable AFM tips and new AFM modes for 3D characterization of critical dimension structures to all potential AFM users. Since the AFM is one of the standard machines in micro- and nanofabrication labs and companies, the project results will allow for a more efficient manufacturing in semiconductor industry and photonics ensuring that the European industry will be at the forefront of the mentioned technologies.