AUTONOMOUS NANOTOOLS – SCANNING SUBMICRON PARTICLES ON MARS

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Scientific methods for investigating nanoscale objects have been advanced with a breathtaking pace during the last two decades. Key in this development of instrument was the plain concept of reducing structural forces and environmental influences by means of dimensional scaling as pioneered in the scanning force microscope. In the beginning, only specialized engineers or scientists could successfully run such instruments, tweaking and optimizing operational parameters during the experiment. Based on that experience, more robust control systems could be developed, reducing the amount of training needed for an operator to work with the instrument. The next step was the development of systems that could run in an automatic batch mode, for example inspecting predefined locations on a wafer for process development in the IC-industry. If we forecast a nanotool based manufacturing, where thousands of miniaturized instruments work in parallel, an even higher degree of autonomy is required. The instrument need to adapt their operational parameters based on information simultaneously collected by sensors and other, neighboring tools.

Our development of an AFM for a planetary mission allowed us taking one step in that direction. The concept of remote planetary exploration does not allow real-time interaction of any kind. A sequence of tasks that need to be executed is compiled on a daily base and up-loaded to the central computer of the space craft. Ideally, this computer then requests for example to collect a sample, deliver it to the AFM and take a series of images. Based on the results, next actions will be taken, e.g. a zoomed-in image of an area of interest. In current missions, this full autonomy has not yet been achieved. We are hampered by the tradition of strictly time based execution of the operation sequence and the potential risk that a fully autonomous operation bears.

Our remote operation AFM was integrated in the Phoenix payload of the current mission of NASA on Mars. The scientific goal of our experiments is to analyze dust and soil particles. This shall contribute to the understanding of the history of water, the gas exchange between the soil and the atmosphere, and the climate on Mars. The mission comprises several imagers that allow looking at Mars at different length scales and providing the context required for interpreting the individual measurements: The surface stereo imager (SSI) generates pictures, which are comparable to what a human explorer would see. It also produces images at different wave lengths. The robotic arm camera (RAC) is attached to the end of the tool that collects soil samples and can be compared to a magnifying lens in terms of its maximal resolution. It can, however, produce more and much different data products as well. The next step on the length scale is the optical microscope (OM) of the MECA instrument suite. It shares the sample stage with the AFM and allows taking images with a pixel resolution of 4 µm. This is sufficient overlap with the AFM scan range of up to 50 µm.

The environmental conditions for the instruments are quit harsh, especially during launch, cruise and landing. The storage temperature ranged from about -120 to +60 C and shocks of up to 2500g peaks had to be survived. We landed safely on Mars and could perform the first AFM measurements (Fig. 1) ever taken on another planet.

Figure 2 shows the MECA microscopy station with the OM on the left, the AFM in the center in front of the objective lens and the sample stage to the right. Figure 3 shows an OM image of

Martian soil. The AFM experiment started only late in the mission and up to now no measurements on real samples were conducted.

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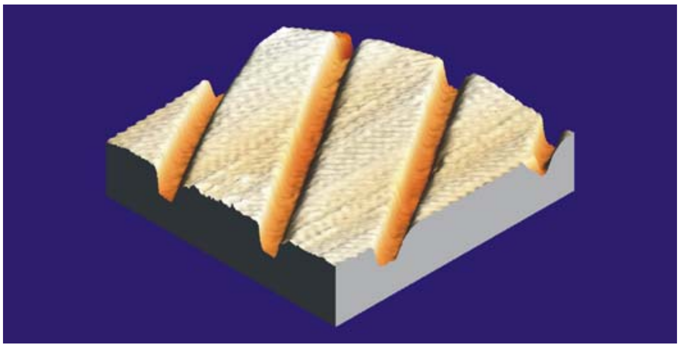

Figure 1 First AFM image of a calibration grid. The pitch is 12µm.

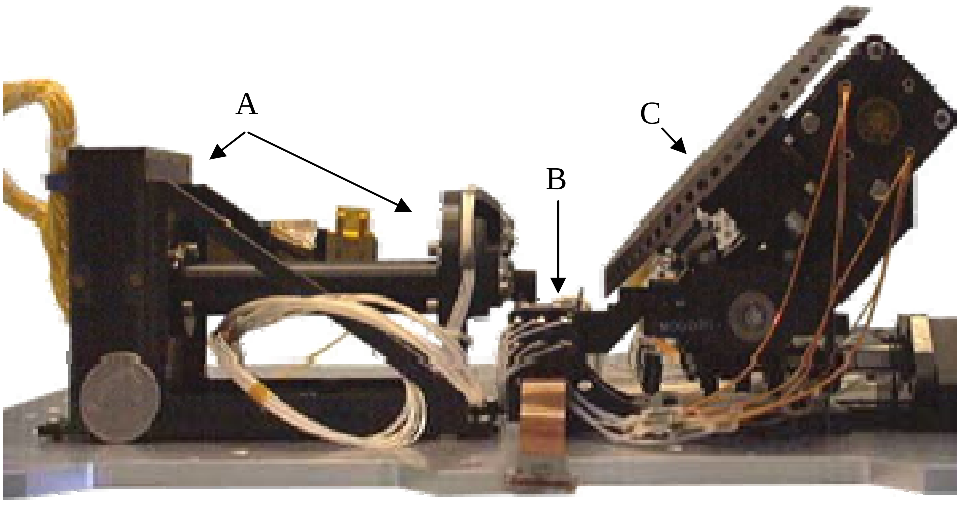

Figure 2 MECA microscopy station. A) optical microscope with from left the camera, tubus and objective lens, surrounded by LEDs for illumination. B) AFM scanner. C) Sample wheel and translation stage.

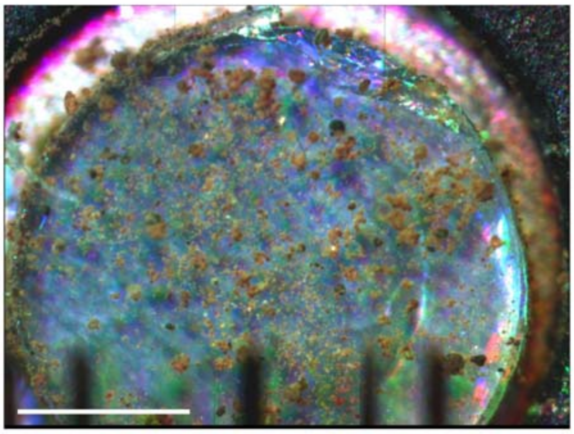

Figure 3 OM image of Martian soil sample. The scale bare is 1 mm long.