Atomic Force Microscope as a tool for nanomanipulation

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Abstract:
An atomic force microscope (AFM) based system has been built for the manipulation of materials at the nanometer scale. The AFM is combined with an inverse optical microscope and an UV-laser microbeam system for photoablation. The actuators of the AFM are controlled using a digital signal processor. Real-time routines and a graphical user interface have been programmed for high resolution imaging and nanomanipulation. The nanomanipulation can be pre-programmed offline or directly performed using a low-cost haptic interface.

Keywords: nanotechnology, actuators, atomic force microscopy, laser ablation, lithography, manipulators.

Introduction

The standard application of the AFM is the imaging of surfaces with subnanometer resolution[1]. Taking advantage of the mechanical contact of the AFM tip with the sample, surface modifications with a resolution much better than the light diffraction limit can be achieved [2-4]. The use of the AFM does not require special preparations of the surfaces to be imaged as compared to other high resolution imaging methods (e.g. electron microscopy). Moreover the AFM works also under liquid environment. Therefore, the field of application of the AFM is very wide, ranging from hard materials surfaces to biological samples in original conditions.
New methods that consider sample properties and tip-sample interaction dynamics are needed in order for a better control of the manipulation process and to obtain reliable results. For complex surfaces e.g. of biological systems, the sample properties exhibit such a strong local variation that predictable surface modification is difficult. The control of the manipulation by the human user using a haptic interface offers a very promising approach.
Laser ablation is a complementary tool in micro patterning. Laser techniques are suitable for hard, brittle and heat-sensitive materials. Pulsed ultraviolet lasers have been applied for ablation of biological samples due to their precision (±2000 Å) with which the depth of the cut can be controlled as well as the lack of thermal damage [5].
Standard AFM systems (hardware and controlling software) are designed to obtain high resolution images. To develop the possibilities of the AFM as a nanomanipulation tool, a new AFM system specifically designed to perform this task has been developed. The use of linearized positioning units for the planar placement of the sample and to control the tip-sample interaction assures the control of the manipulation process with nanometer accuracy. The direct observation of the sample using an inverted light microscope widens the range of its applications from hard materials surfaces to biological sample in natural conditions. The open-design philosophy of the system allows the application of different methods for the tip-sample interaction detection (e.g. laser interferometry). The use of a joystick and haptic interfaces open a new way of sample manipulation at the nanometer scale [6].

Nanomanipulator Design

A digital signal processor (DSP) unit (Adwin-Gold, Jäger Computergesteuerte Meßtechnik GmbH) is used as a flexible controller. The DSP algorithms have been specially developed for the application of the AFM for nanomanipulation using the pseudo-BASIC language AdBasic. A graphical user interface has been programmed using Visual C++. During imaging the user has online information about the exact tip position. The software offers two different approaches to perform surfaces modifications. The first is to set previously the surface modifications parameters. The second is to take control manually of the AFM through a joystick system while the user obtains online feedback of the tip-sample interaction using a haptic interface.
A piezoelectrically driven XY flexure positioner is used to position the sample in the planar coordinates with 1 nm accuracy in 100 µm range (P-517 PZT Flexure Stage, Physik Instrumente GmbH&Co.). As vertical positioner a piezoelectrically driven stage actuator is used with an accuracy of 0.01 nm over 25 µm range (P-753 LISA NanoAutomation Stage Actuator, Physik Instrumente GmbH&Co.). For very fast modulation of the AFM cantilever a dither piezo is used (10x5x0.5 PICA51, PI Ceramic GmbH).

The whole system is placed on the top of an inverted microscope (Axiovert 100S, Carl Zeiss).
As haptic interface a low cost force feedback joystick is used (WingMan Force, Logitech).
For laser ablation an UV microbeam laser (P.A.L.M. Mikrolaser Technologies AG) is focused on the sample through the microscope objective using the fluorescence illumination path via two high power beam splitters.

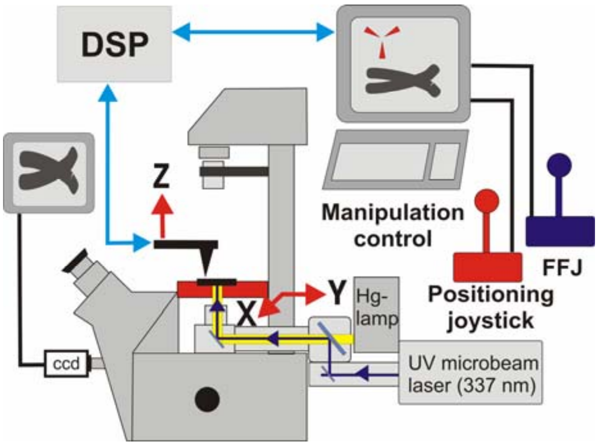

***Fig. 1**: System layout*

System performance

High resolution imaging can be accomplished operating the system as a standard AFM. The user visualize the data on real time and can switch the system for manipulation during imaging. The AFM tip is positioned with 1 nm accuracy in the planar coordinates and 0.01 nm vertically.
Manipulation can be accomplished in lithography mode or online guided by the user using the joystick system. In the lithography mode the user set the trajectory of the tip and parameters for controlling the tip-sample interaction during manipulation. By the user guided manipulation, the user takes control of the tip by a positioning joystick and get the tip-sample interaction though the haptic interface. Non-mechanical manipulation can be performed using the UV-laser unit, the results of the ablation are directly observed using the AFM.

Conclusion

Developing the AFM as a tool for the modification of surfaces in a predictable and reliable manner open a wide range of new applications. Some of those are high resolution lithography, nanostructuring, construction of nanodevice and direct access of nanobiological systems.

References

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