Micro- and nanomanipulation inside the SEM

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Abstract. Based on individual piezodriven nanomotoric units a nanomanipulation platform
is integrated into a low voltage field emission SEM (Zeiss Gemini). The instrumentation allows
the controlled movement of individual particles (ca. 50 nm), the cutting of ultrathin polymer
membranes or the deformation of hollow polymer spheres with an ultrathin elastic membrane
(ca. 20 nm thickness). Interaction with the objects can be done under direct microscopic
observation. Imaging up to 20000 x magnification without any detectable influences of external
vibrations guarantees the precise manipulation. Under appropriate imaging conditions (e.g.
using low energy electrons) specimen charging can be avoided and even uncoated glass tips can
be used to manipulate samples.

1. Introduction
In micro- and nanotechnology the SEM becomes more and more important not only as an
analytical imaging tool but also as an assembly unit for micro- and nanoparts and also
as a laboratory unit for physical measurement of electrical properties as for example the
conductivity of metallic nanorods [1] or mechanical properties such as adhesion of micrometer
sized particles [2]. Beside from these new demands classical analytical applications in materials
could profit from a hand inside the SEM. Such applications could be separation of particles
from a surface in order to analyze the burden surface areas, separation of particles for EDX
analysis of the isolated particles, lifting a surface coating for inspection of the underlying surface
etc. The precise assembly and handling of micrometer or even submicrometer components
of microanalytical or microassembly systems requires both microscopic techniques of suitable
resolution and manipulation tools with submicrometer or better nm positioning capability.
While light microscopy only allows manipulation on a micrometer scale and AFM techniques
are used on an atomic scale modern SEM techniques fill the gap for manipulation of objects
between micrometer and nanometer size. In-situ SEM experiments and micromanipulation
operations with non-conducting specimen require surface-charge-free imaging conditions which
are either realized in an ESEM [3] or in an low-voltage SEM (LVSEM). Based on experiences
in SPM techniques piezodriven motor units [4],[5] are commonly used for fine positioning with
nm resolution. Single manipulation units can be arranged in different geometries [6] and the
integration of microfabricated grippers [7] allows the pick up of submicrometer sized objects.
Our work focuses on the integration of a commercial nanomotoric unit into the SEM and
its combination combination with LVSEM for manipulation of non-conducting and uncoated
materials.
1.1. The nanomanipulation units
A recently developed piezodriven manipulation unit (needle manipulator) is used in our experimental setup and schemed in fig.1. It consists of two pairs of independent uniaxial moving nanomotors (A,B) working as a tilting table (C) and a central nanomotor (D) for z movement. The special mechanical design of the piezotube of the nanomotor and the introduction of shock waves into the system allows movements on mm range with nm precision. The individual nanomotor used in this setup basically combines an inner mobile tube which is in adhesive contact with an outer stationary tube made from piezoceramic. A voltage up to 30 V applied to the piezoceramics elongates this tube according to the piezoeffect and moves the mobile tube up to 200 nm. For larger movements up to 10 mm a saw tooth voltage with an optimized frequency is applied. The slow increase in voltage moves the inner tube as described while the sudden drop in voltage causes the piezoceramic to relax to the contracted position while the mobile tube does not follow this relaxation due to inertia.

![Figure 1. Needle manipulator with 5 piezodriven nanomotors](image1.png)

![Figure 2. Two needle manipulators mounted inside a Zeiss Gemini SEM](image2.png)

1.2. Integration into the SEM
The needle manipulation units (Klocke Company) were integrated into a Zeiss DSM 982 (Gemini) Low Voltage Scanning Electron Microscope (fig.2). A commercial available microbench system (LINOS) was used as mounting support for the manipulator units. The needle manipulators were mounted in lens-holders that could be easily connected to the clamping fixture and that is directly attached to the microscope front door of the SEM chamber with the flanged coupling for electrical conduction. The standard parts of the microbench system allow all preadjustements that are necessary with respect to the sample and to the prepositioning of the manipulators with respect to the electron optical system. The sample can be moved with the standard stage and the manipulator system as described is an excellent tool for manipulation tasks under microscopic control but it has no absolute control or measurement of the actual coordinates of the manipulator unit.

2. Experimental examples of micromanipulation inside the SEM
2.1. Cutting of ultrathin free standing polymer films
As demonstrated in fig.3 a-c a polystyrene film of 50 nm thickness covering a microreaction chamber can be cut precisely. Although polystyrene is a brittle polymer material the cutting
process causes no crack or craze formation because of the different deformation behaviour in ultrathin films.

![Figure 3](image3.png)

**Figure 3.** Cutting of ultrathin free standing polystyrene film in the SEM

2.2. Piercing of thin-walled polymer microcapsules

Active agents can be encapsulated in ultrathin-walled polymer microcapsules. In order to release the compounds or even to use the microcapsules as microreaction vessels suitable tools like ultrathin tips or electrodes for electrochemical reactions need to be pushed through the delicate particle membranes in order to transport agents into the capsule or to release agents from the capsule into another microsurrounding. As demonstrated in fig.4 a-c a glass capillary commonly used for microinjection purposes is piercing the membrane of the microcapsule under SEM observation. The submicrometer sized hole through the membrane that has been introduced by the microcapillary is indicated with an arrow (fig.4 c). It could be shown that the microcapsule is deformed elastically without pushing through by extremely careful approach of the tip.

![Figure 4](image4.png)

**Figure 4.** Piercing of polymer microcapsules by ultrafine-positionable microtools (glass capillary, microelectrode) inside the SEM. The arrow indicates the submicrometer hole produced by the glass capillary

2.3. Transportation of microparticles inside the SEM

A precise glue joint between different polymer microparts can be produced by the transportation of microcapsules containing the adhesive compound which can be released by bursting of microcapsules on well defined positions. An example for precise transportation of different
microspheres inside the SEM is shown in fig. 5 in which isolated particles are moved precisely on the submicrometer scale.

Figure 5. Transportation of 4 \( \mu \)m sized particles

2.4. Electron microscopic requirements for micromanipulation of non-conducting materials

Although the objects of interest are generally sputtercoated to avoid surface charging moving of particles creates uncoated surfaces which are charged by electron irradiation. This undesirable effect can be avoided either by working under reduced vacuum conditions or at low electron beam energies \( E_0 < 1\text{keV} \) as done in this study. We could observe that even under low-voltage imaging conditions non-conducting tips used for sample manipulation and non-conducting polymer particles are charged negative due to interaction with the electron beam. As a consequence the particles are already repelled by electrostatic interactions between tip and particles before they contact. This for manipulation purposes undesirable effect can be overcome using conducting tips.

Summary

A nanomanipulation tool has been integrated into a low voltage scanning electron microscope which guarantees the imaging of non-conductive uncoated polymer materials without charging effects. Controlled particle movement and deformation of hollow microspheres as well as cutting of ultrathin films has been demonstrated.

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