Compact and high efficient secondary ion mass spectrometer with quadrupole traps for electron microscopes to combine structural and analytical imaging

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Introduction

Combining structural imaging with analytical imaging opens new doors in modern natural science. An electron microscope uses a focused electron beam (FEB) for structural imaging. For nano-scale manipulation of surfaces a focused ion beam (FIB) is used. During processing a small amount of secondary ions are produced which can be used for mass spectrometry (SIMS).

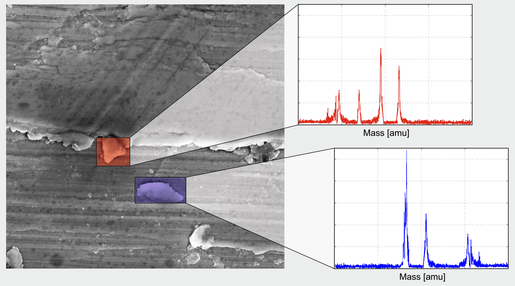
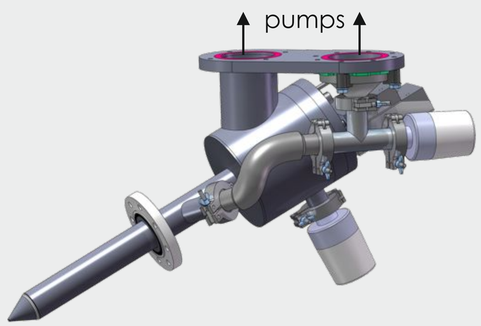


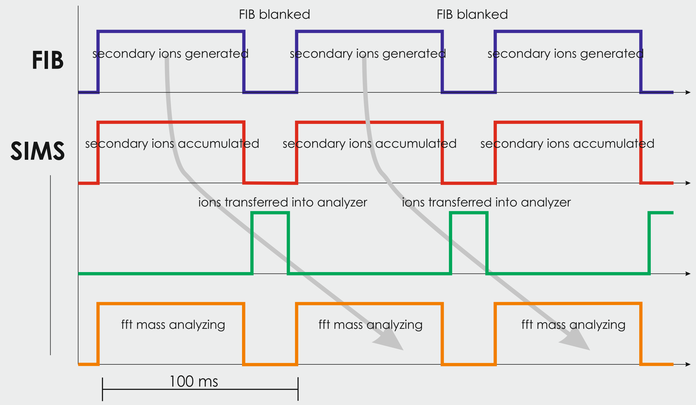
illustration of a surface image with combined mass analysis

System design and measurement sequence

- SIMS is an independent add-on device, but must not influence the microscope capabilities.
- All electrical and mechanical feed throughs are done with a single flange
- SIMS is hardware triggered by the FIB to start measuring
- During surface processing secondary ions are collected and accumulated
- Secondary ions are transferred into the mass analyzer while FIB is blanked (off)
- Previously trapped ions are analyzed during next collecting and accumulating time slot

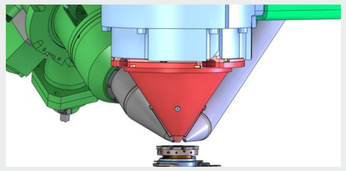


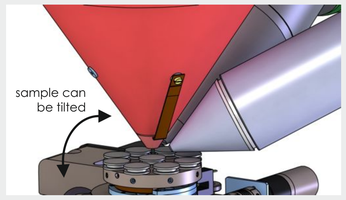
compact and fully integrated SIMS-device



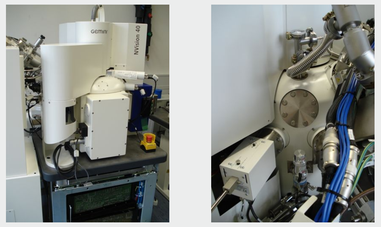
System requirements and constraints

Very limited space





limited space inside the microscope
☛ mass analyzer must be placed outside
☛ transfer optic needed

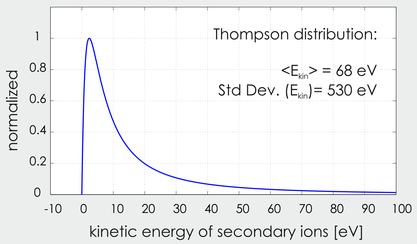


limited space at the outer housing of the microscope
☛ compact design needed

Secondary ion beam

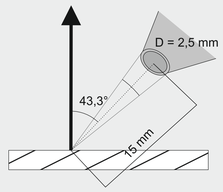
Low current secondary ion beam
typical primary ion beam: 4 nA ... 500 pA
typical secondary ion beam yield: 2 ... 0.25 pA, e.g. $1x10^6$ ... 1.5×10^5 ions per 100 ms
☛ **high efficient transfer optic needed**

High kinetic energy distribution



☛ cooling with damping-gas required

Adverse ion beam direction



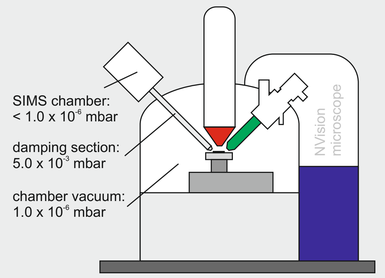
Cosine-distribution:
Only 0.44% of secondary ions have suitable direction to the SIMS orifice

☛ extraction lenses needed

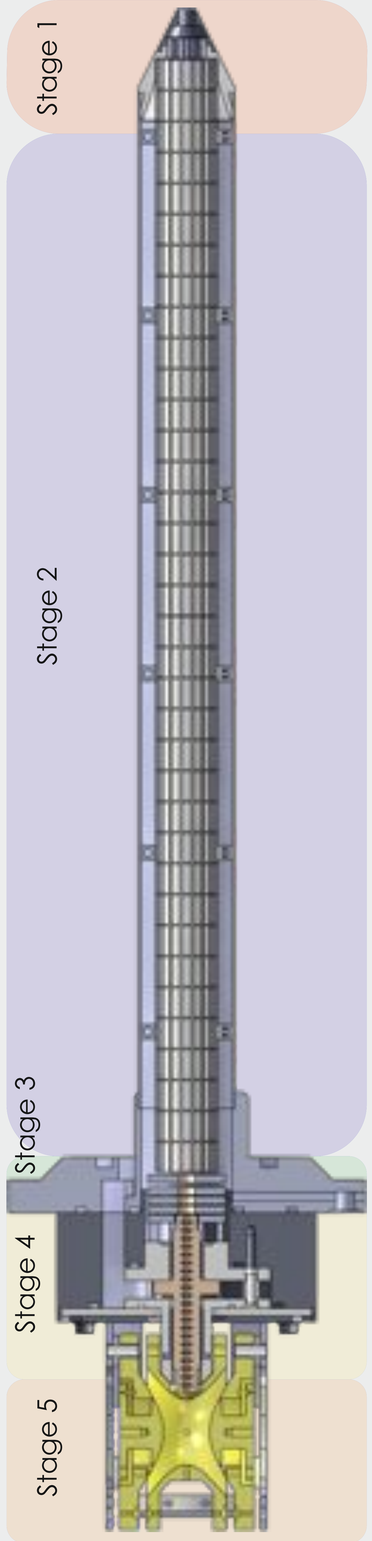
Difficult vacuum condition

- damping section with fine vacuum required
- ultra high vacuum needed for high resolution imaging
- mass analyzer requires ultra high vacuum, too

☛ pressure stages needed

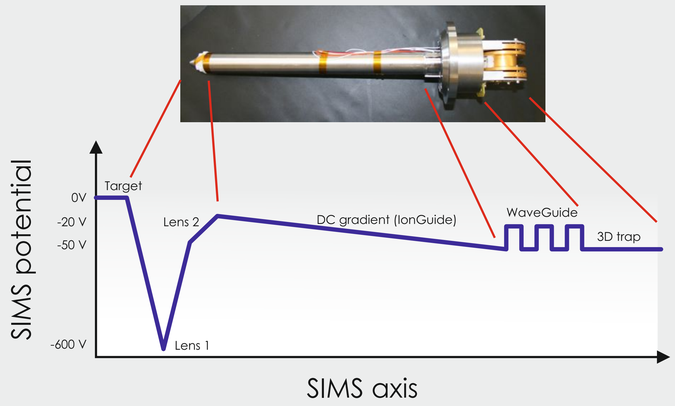


System construction and dimensioning



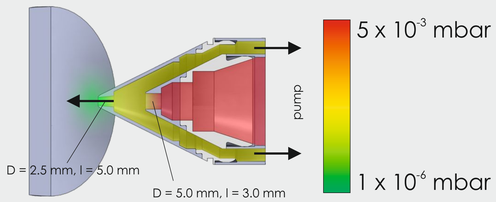
System potentials: Overview

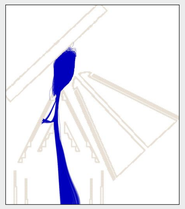
To avoid high secondary ion divergence after extraction the ions are not shifted to ground potential. Thus the entire system is shifted by about -50V (including 3D trap).



Stage 1: Extraction lenses

Two electrostatic lenses focus the secondary ions into the SIMS. The lenses incorporate also a differential pressure stage to separate target and cooling section.

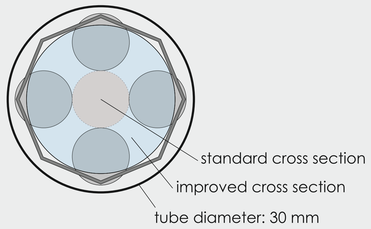


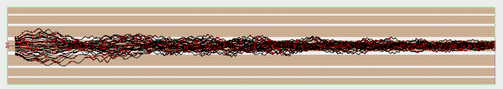


Stage 2: Ion transfer and cooling

A 342 mm octagonal shaped linear quadrupole trap made with PCBs (IonGuide) guides the ions to the accumulation section.

The ion trapping cross section (diameter 18 mm) is 30 to 50% bigger compared to common linear traps made with rods.

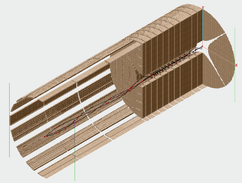




The ions are cooled down with helium as damping gas (10 sccm) and radial bunched by the quadrupole field.

Stage 3: Multihyperbolic Quadrupole slice

To effectively reduce the core diameter of the traps two multihyperbolic slices are used. Electrically the field is not distorted.



diameter reduction:

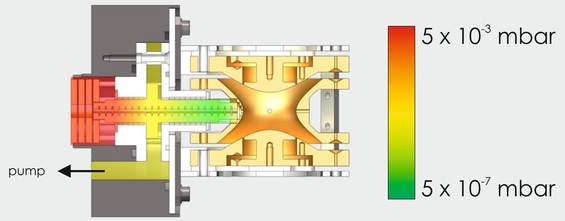
18.0 mm → 5.0 mm → 1.5 mm

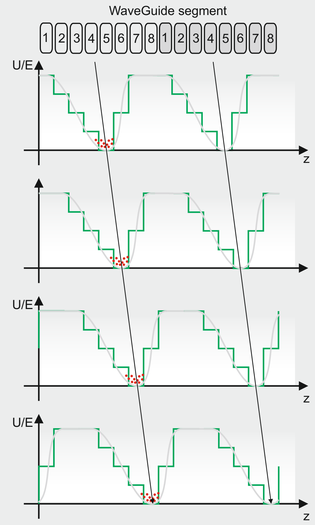
Stage 4: WaveGuide and pressure stage

Stacked quadrupole slices are used for realizing a potential well at the end of the IonGuide section. This section is used for accumulation. The ions are radially and axially bunched.

After accumulation the ions are transferred within the potential well by an axially segmented linear ion trap (WaveGuide).

The focused ions are transferred through a differential pressure stage into the 3D ion trap for analyzing.





Stage 5: Fourier transform 3D quadrupole ion trap

The Fourier transform 3D quadrupole trap is used to measure the influence charge of stored ions and is similar to ICR.

This method features a high dynamic range and a high mass resolution in combination with a very compact design.