Metrological Characterization of a Sensitive Secondary Ion Mass Spectrometer for Electron Microscopes to Combine Optical/Structural and Analytical Imaging

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Introduction

Overview:

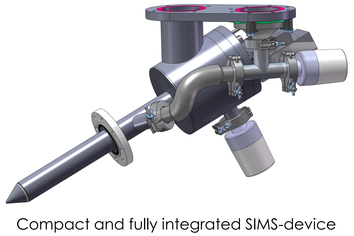
In many applications the combination of optical/structural and analytical imaging of the same target at the same time is desirable. In an electron microscope a focused electron beam is used for optical imaging. For nano-scale surface processing and advanced structural imaging a primary focused ion beam (FIB) is used. The FIB produces a small amount of secondary ions, which can be used for spatially resolved mass spectrometry.

Challenges:

- Limited space
- Low secondary ion beam currents (typical 1 … 5 pA)
- Broad kinetic energy distribution of the secondary ions
- Difficult vacuum conditions

Approach:

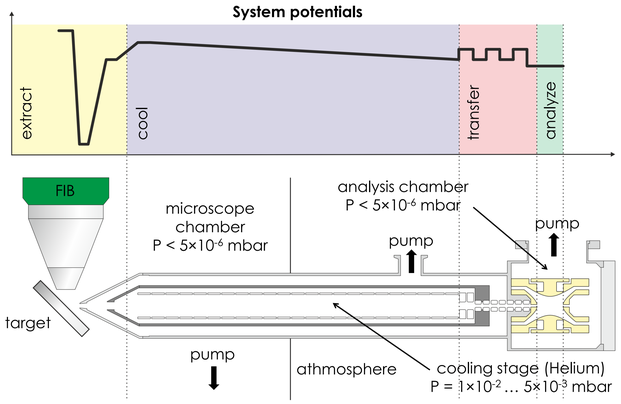
- Helium cooling section to minimize energy distribution width
- Extraction lens configuration [1]
- Axial segmented linear quadrupole trap made in planar technology [2] for ion transfer
- Pressure stage incorporating a quadrupole ion wave guide for ion transfer between different pressure regions
- 3D-Ion trap used in Fourier Transform mode as mass analyzer



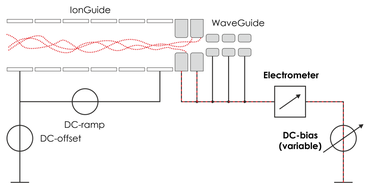
Compact and fully integrated SIMS-device

Principle of Operation

I. Secondary ions are continuously generated by the FIB
II. Secondary ions are accelerated into the SIMS orifice [1]
III. Ions are cooled and bunched in the IonGuide
IV. Ions are accumulated and sequentially transferred/pulsed into the mass analyzer (3D-trap)
V. Ions are analyzed by measuring their influence charge on the cap electrodes [3]



Methods for Stage-by-Stage Characterization



IonGuide

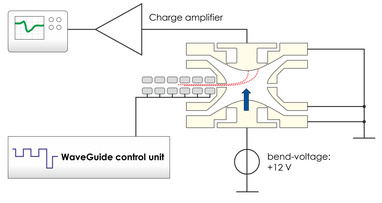
Ionization:
electron beam ionization (tungsten filament) of Argon/Krypton outside the SIMS device

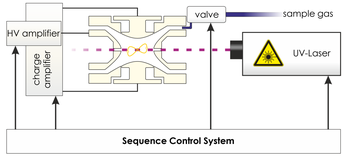
Ion detection:
WaveGuide electrode used as Faraday-Cup

WaveGuide

Ionization:
electron beam ionization (tungsten filament) of Argon/Krypton outside the SIMS device. IonGuide used for ion transfer to WaveGuide

Ion detection:
Cup electrode of 3D-trap used as Faraday-Cup



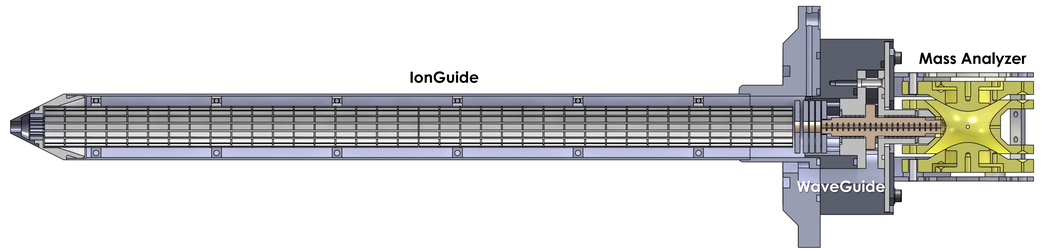


3D-Trap

Ionization:
266nm UV Laser for in-situ ion generation of vapor phase converted aromatic hydrocarbons

Ion detection:
Measuring the influence charge of trapped ions

Cross Section of the SIMS Device



IonGuide

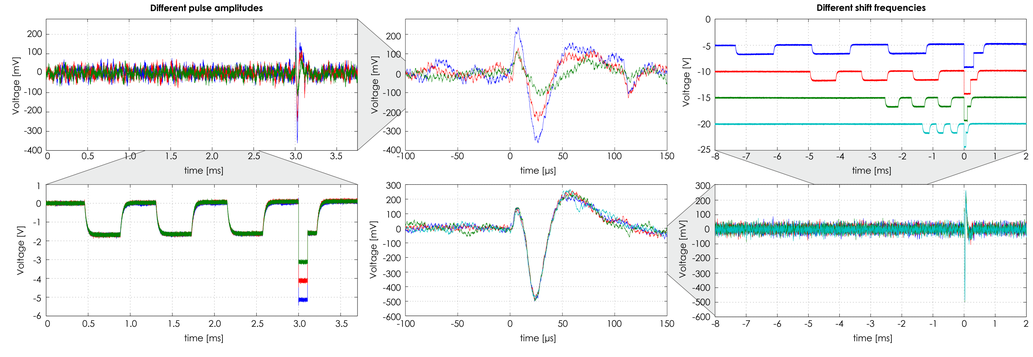
- System dimensioning of the complete transfer chain using SimIon
- Hard sphere model to simulate collisions and cooling efficiency

- DC ramp affects kinetic energy equilibrium
- High DC ramps → high kinetic energy

- Low helium pressure causes broad kinetic energy distributions

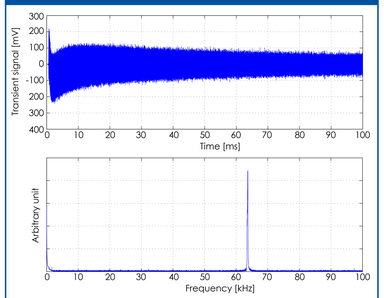
- Measurements show higher kinetic energy than numerical simulations
- Difficult to determine field distortion- and RF-effects

WaveGuide

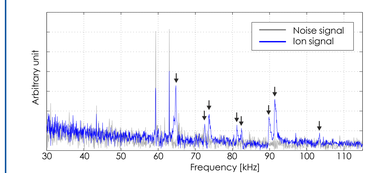


- Ions are shifted and pulsed into the 3D-trap
- High pulse amplitudes → strong signals
- Ions are transferred with different shift frequencies
- Shift frequency does not affect transfer efficiency

3D-Ion Trap



Transient signal and spectrum of in-situ generated benzene-ions



mass spectrum of FIB sputtered ions (complete transfer chain)

Conclusions

- **WaveGuide:** Enables transfer of cooled and bunched ions between different pressure regions
- **IonGuide:** Kinetic energy equilibrium depends on DC ramp of the IonGuide
- **IonGuide:** High helium pressure minimizes kinetic energy distribution of ions
- **3D trap:** Compact and highly efficient wideband mass analyzer
- **SIMS:** Complete chain tested under typical lab conditions → proof of concept adduced

Future work:

- Improve and extend low mass range
- Improve pressure stages to enable high resolution measurements (longer signal transients)
- Improve dynamic mass range

References

[1] Preikszas, D.; Aliman M.; Mantz, H.; Laue, A.; Brockhaus, A.; Glasmachers, A. *Optimization of the collection efficiency of secondary ions for spartially resolved SIMS in Crossbeam devices*, **12th International seminar on Recent Trends in Charged Particle Optics and Surface Physics Instrumentation**, 2010

[2] Glasmachers, A.; Laue, A.; Brockhaus, A.; Puwey, A.; Aliman, M. *Planar technologies for optimized realizations of quadrupole ion guides and quadrupole ion wave guides*, **58th ASMS Conference**, 2010

[3] Laue, A.; Glasmachers, A. *New Design of a Compact Fourier-Transform Quadrupole Ion Trap for High Sensitivity Applications*, **57th ASMS Conference**, 2009

[4] **Patent application EP11152379.1 – 1232:** *Apparatus for focusing and for storage of ions and for separation of pressure areas*, 2011

[5] **Patent application EP11152420.3 – 2208:** *Apparatus for transmission of energy and/or for transportation of an ion as well as particle beam device having an apparatus such as this*, 2011