AN EBIS-BASED LOW-ENERGY ACCELERATOR FACILITY FOR FINE-FOCUSSED HIGHLY CHARGED ION BEAMS

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MC-8: Applications of Accelerators, Technology Transfer and Industrial Relations

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Dreebit

Overview

- Introduction
- HCI-FIB Setup
- Electron Beam Ion Sources (EBIS)
- Focused Ion Beam (FIB) Optics
- Experimental Results
- SEM Imaging
- Emittance Measurement
- Outlook

Introduction

- Technologies based on Focused Ion Beams became very widespread throughout research and industrial sectors

- Modification and analysis of targets with one device possible

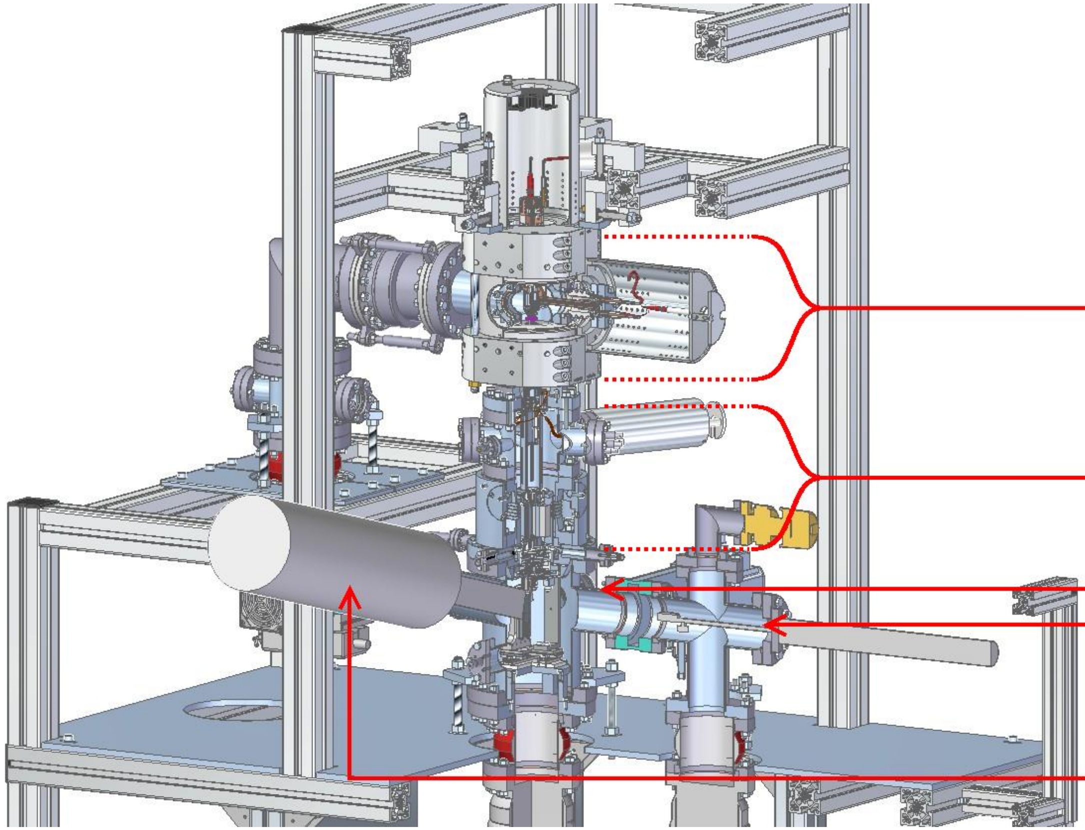
- Advantages of Room-temperature EBIS:
  - Broad kinetic energy range up to MeV
  - Virtually all elements usable as projectiles
  - Production of highly charged ions (HCI) possible
  - Tabletop size

HCI-FIB Setup

Overview

HCI-FIB Setup

Overview



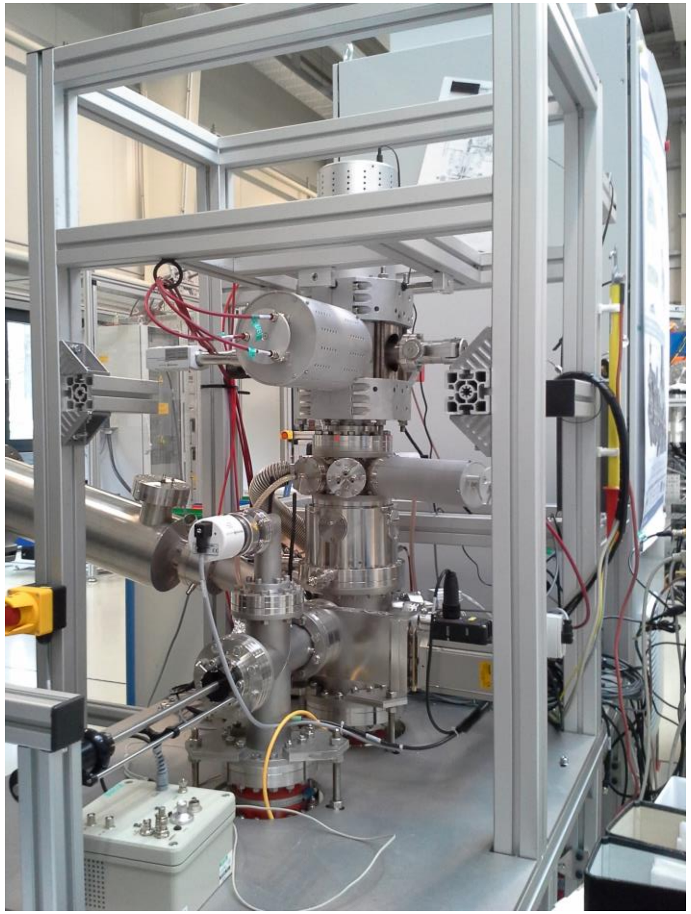
Electron Beam Ion Source

Focused Ion Beam Optics

Target Chamber

Transfer Chamber

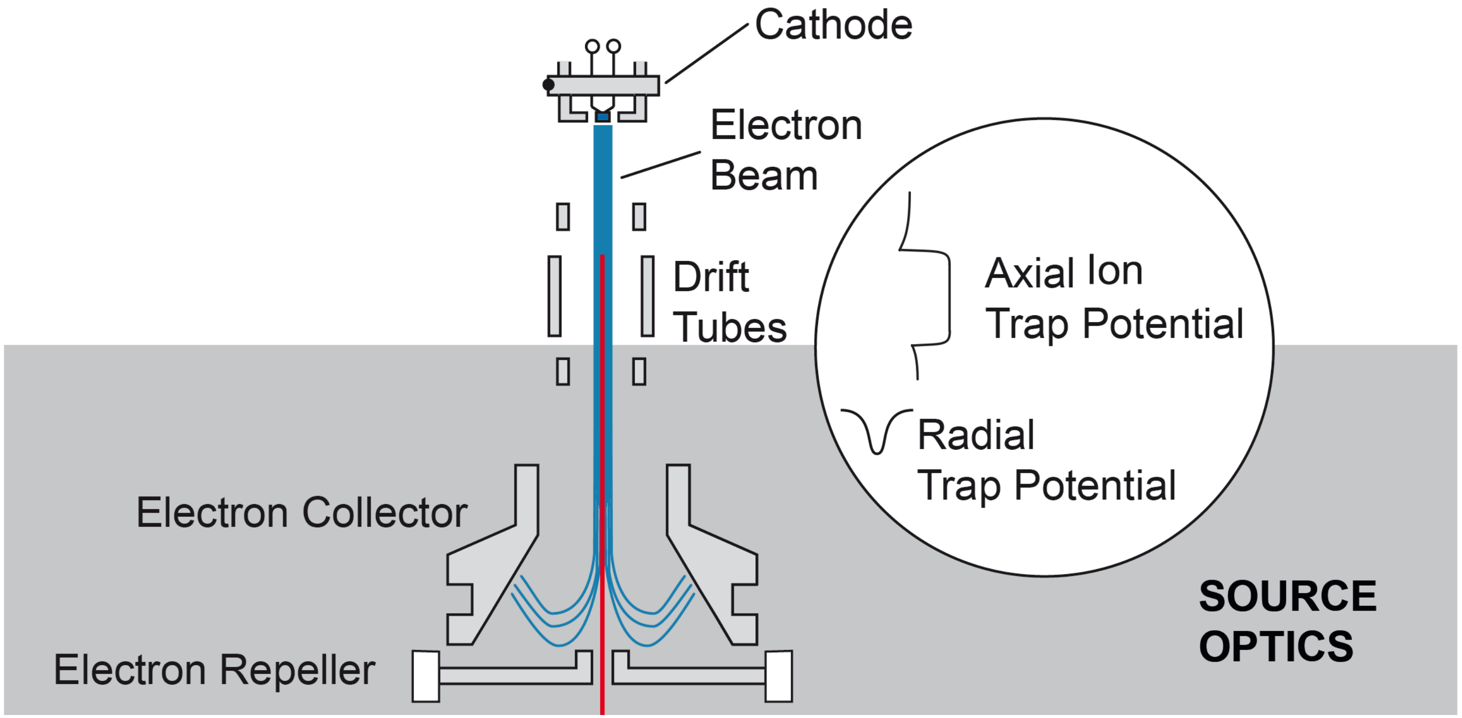
Time-of-Flight Spectrometer



HCI-FIB Setup

Dresden EBIS – Basic Principle

- Ionization via high-density electron beam
- Pulsed mode (μs) and DC mode ion extraction



- Electron beam energy up to 25 keV allows for production of Highly Charged Ions (HCIs)
- Small kinetic ion energy distribution < 10 eV
- Small ionization area -> high ion beam brightness

HCI-FIB Setup

Dreebit EBIS-M

- Max. electron current: 50 mA *
- Max. electron energy: 25 keV

- Magnet system: NdFeB permanent magnets (bakeable)
- Magnetic induction on axis: 500 mT

- Trap length: 60 mm
- Ionization factor: $> 1 \cdot 10^{21}$ e/cm²

- Specially designed third drift tube for optimal alignment

* Use of larger cathode possible but without reasonable advantages

HCI-FIB Setup

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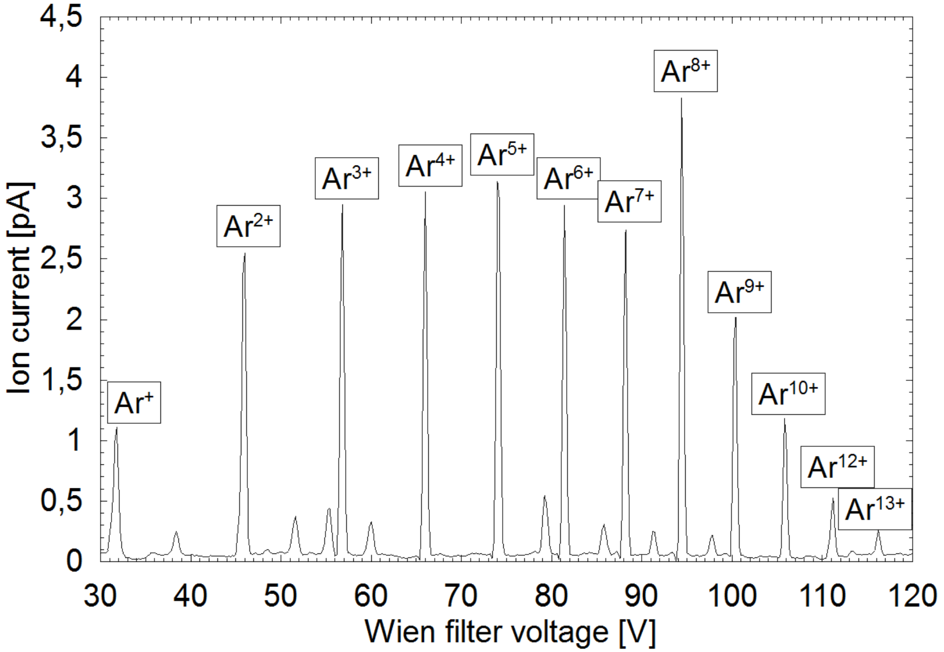
- Maximum charge state determined by ionization factor, ionization time, and pressure

- Highest charge states available in pulsed mode:

Element	Max. charge state q
Argon	18+
Krypton	36+
Xenon	46+
Gold	69+
Iridium	71+

- Intermediate charge states in DC mode:



HCI-FIB Setup

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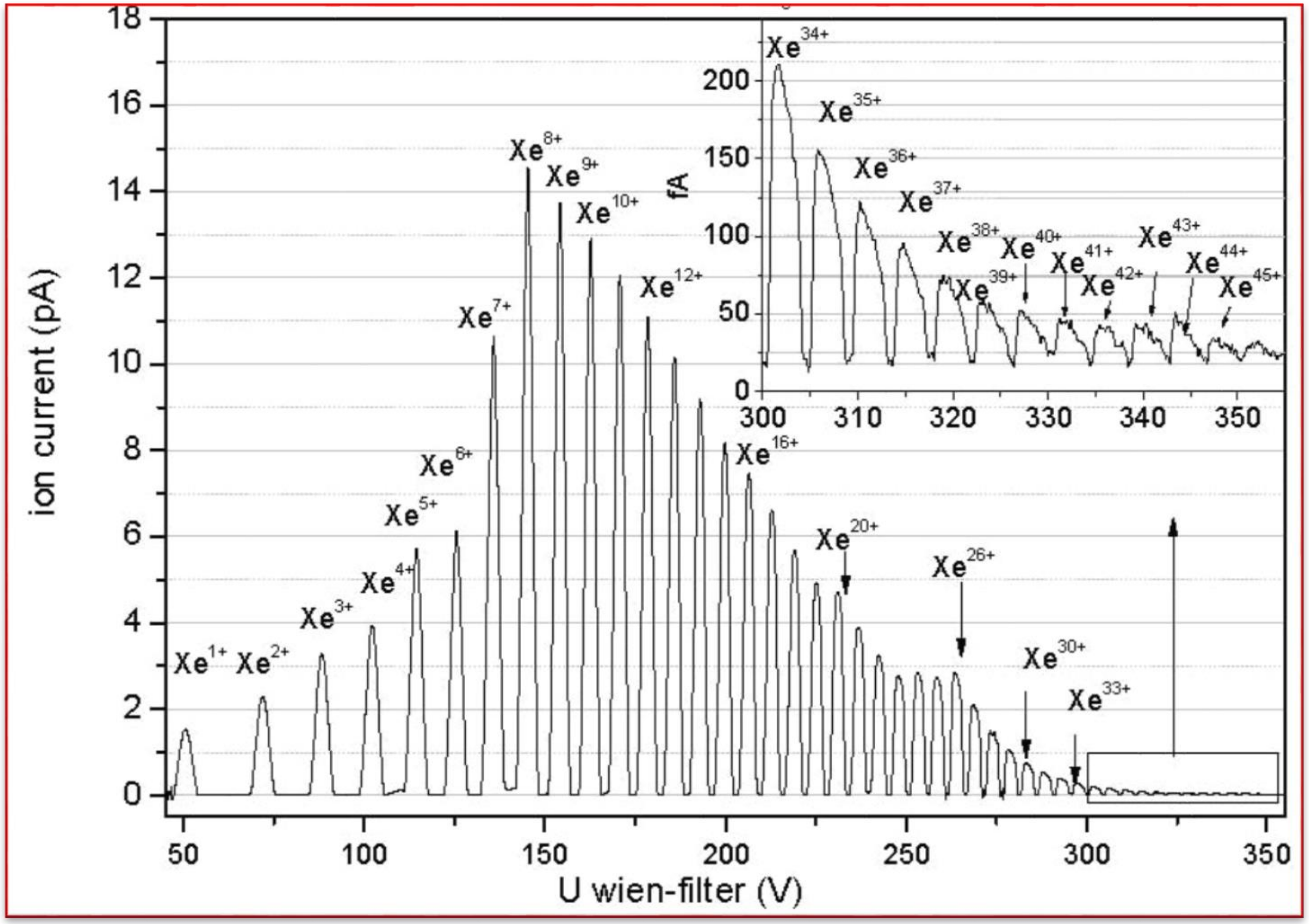
- Maximum charge state



HCI-FIB setup

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- Kinetic energy determined by charge state q and acceleration potential U_0
  $$E_{kin} = q \cdot U_0$$
- U_0 variable between 5 and 20 kV

Element	Max. charge state q	Kin. energy [keV]
Argon	18+	360
Krypton	36+	720
Xenon	44+	880
Gold	69+	1380
Iridium	71+	1420

HCI-FIB

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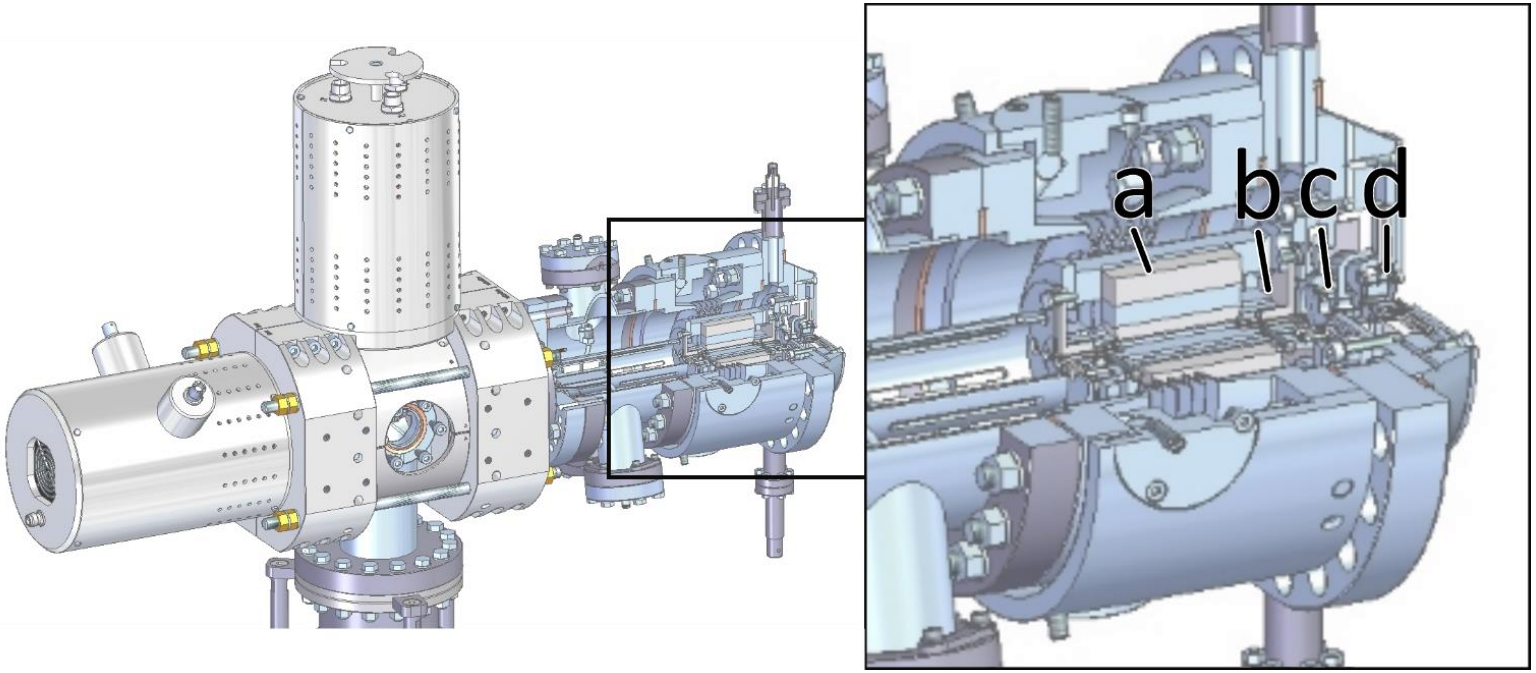
- Potential energy determined by charge state
- Charge state selection via Wien filter
- Can induce certain effects on surface impact (special structures, increased sputter and secondary ion yield)

Element	Max. charge state q	Kin. energy [keV]	Potential energy [keV]
Argon	18+	360	14.4
Krypton	36+	720	75.8
Xenon	44+	880	51.1
Gold	69+	1380	205.5
Iridium	71+	1420	226.6

HCI-FIB

Focused Ion Beam Optics

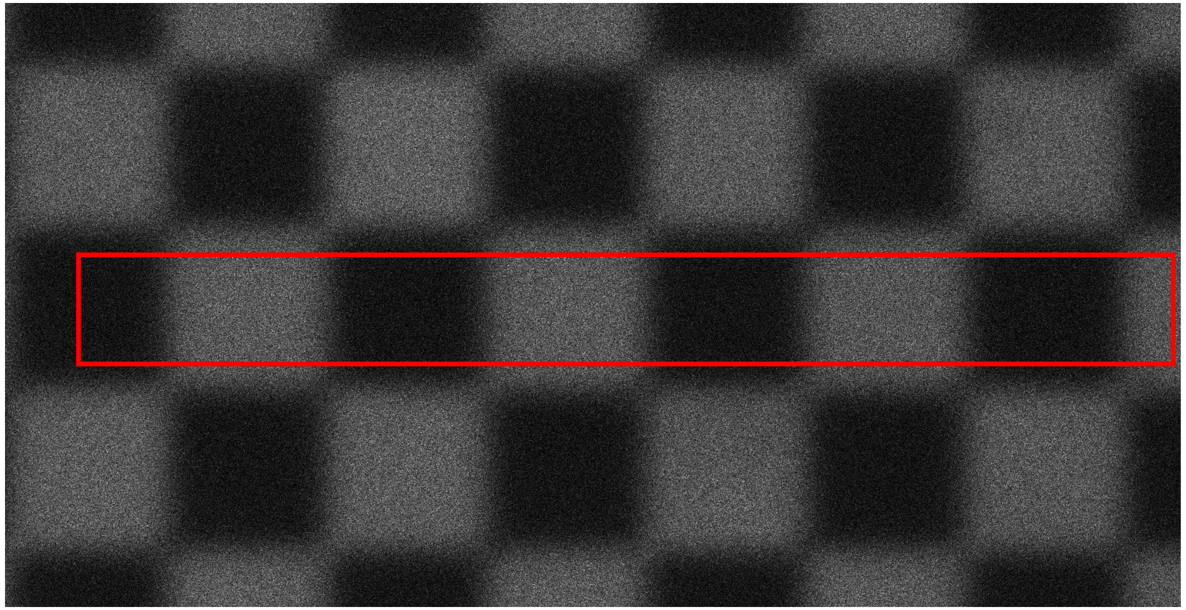


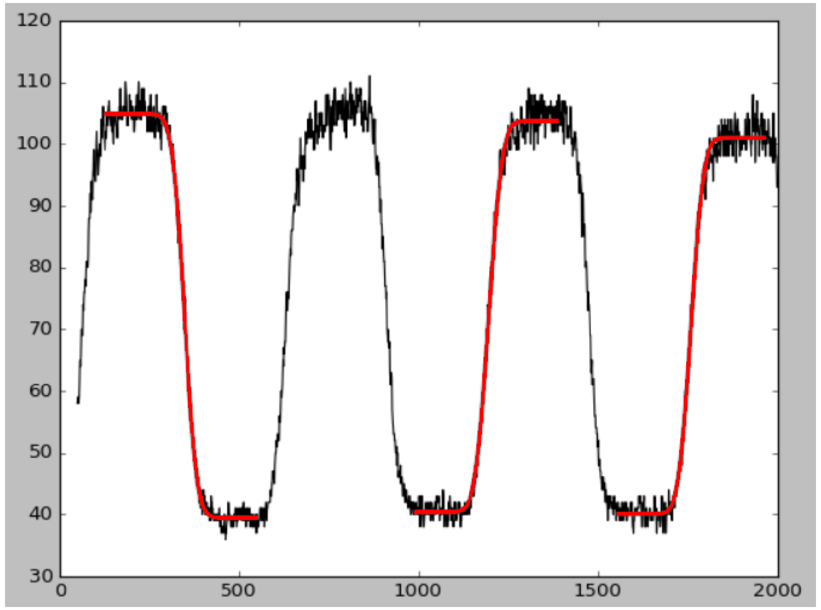
a – Wien filter
b – Aperture
c – Einzel lens
d – Octupole

Experimental Results

Beam Width

- Determination from SEM image of a golden chessboard pattern on silicon
- Analysis of slopes in the intensity distribution





Properties

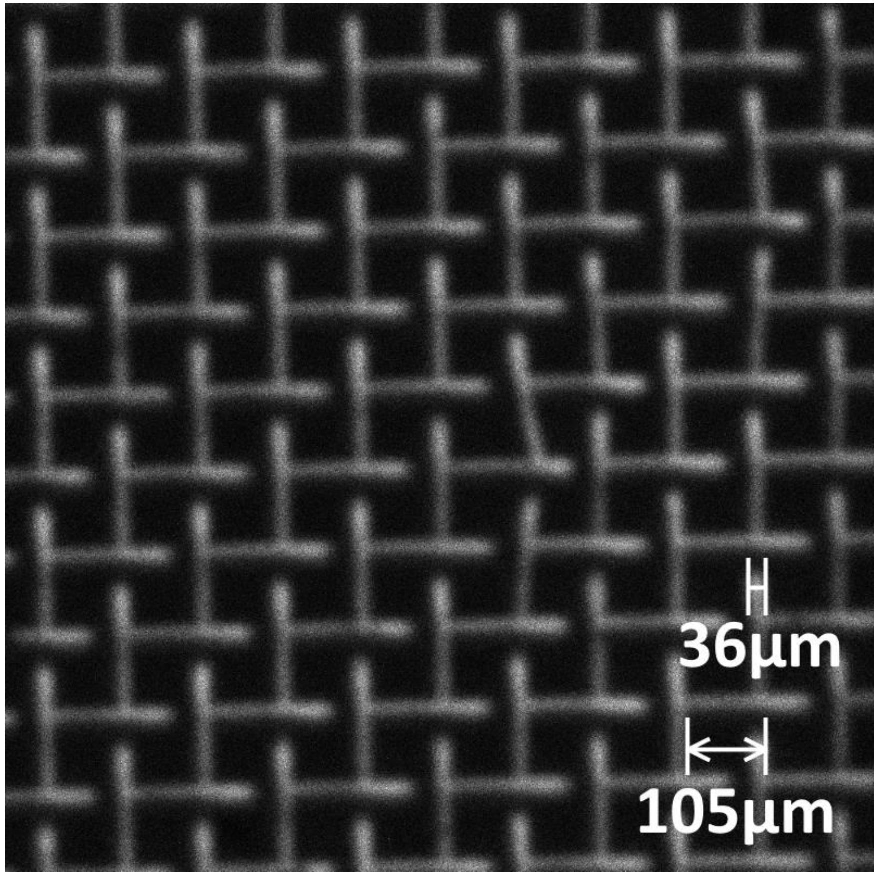
Beam Width

- Lower beam width comes with lower transmitted ion current and vice versa

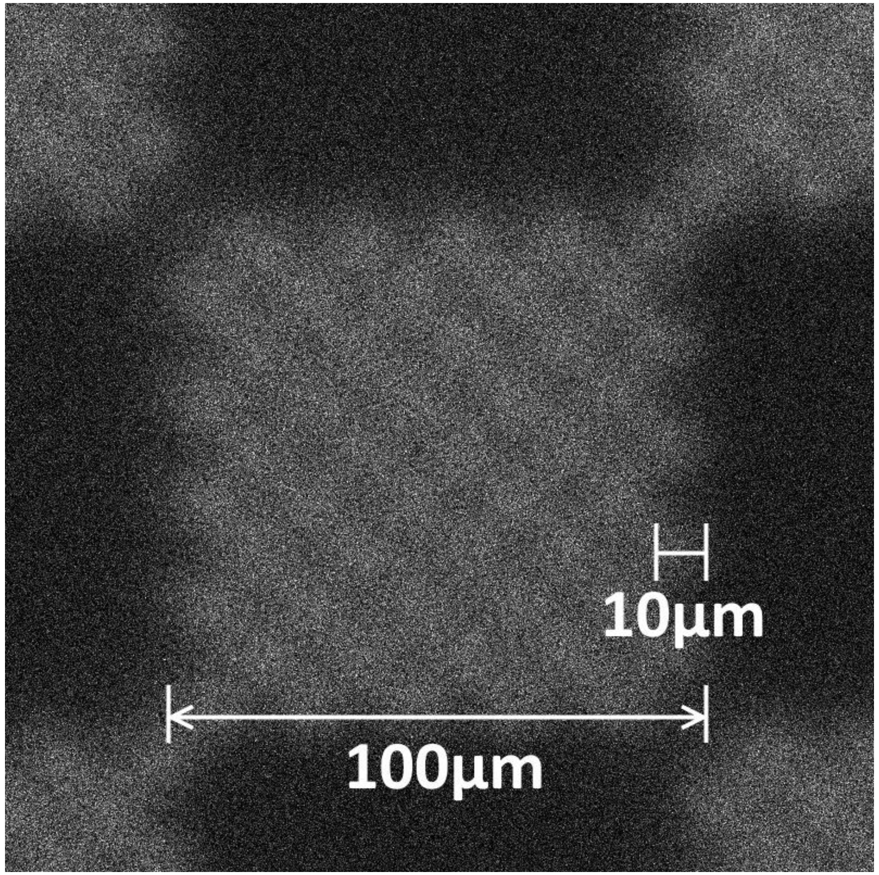
Aperture [µm]	Beam width [µm]	Ion beam current [pA]
1000	< 1000	> 500
1000	40	> 300
100	< 20	10

Experimental Results

SEM imaging



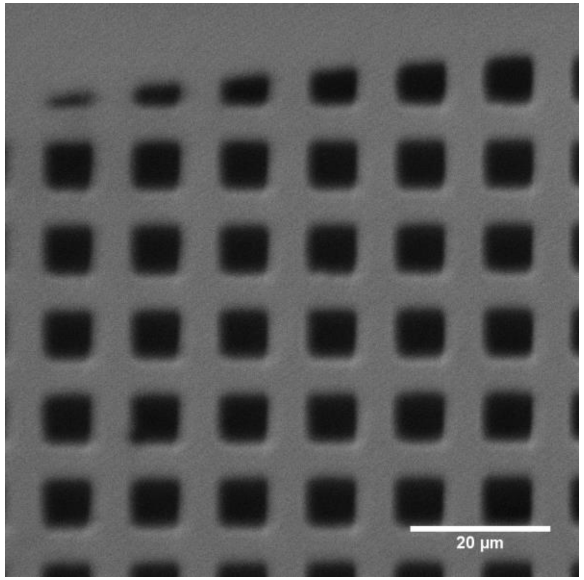
10 pA He^{1+}, E = 9.6 keV

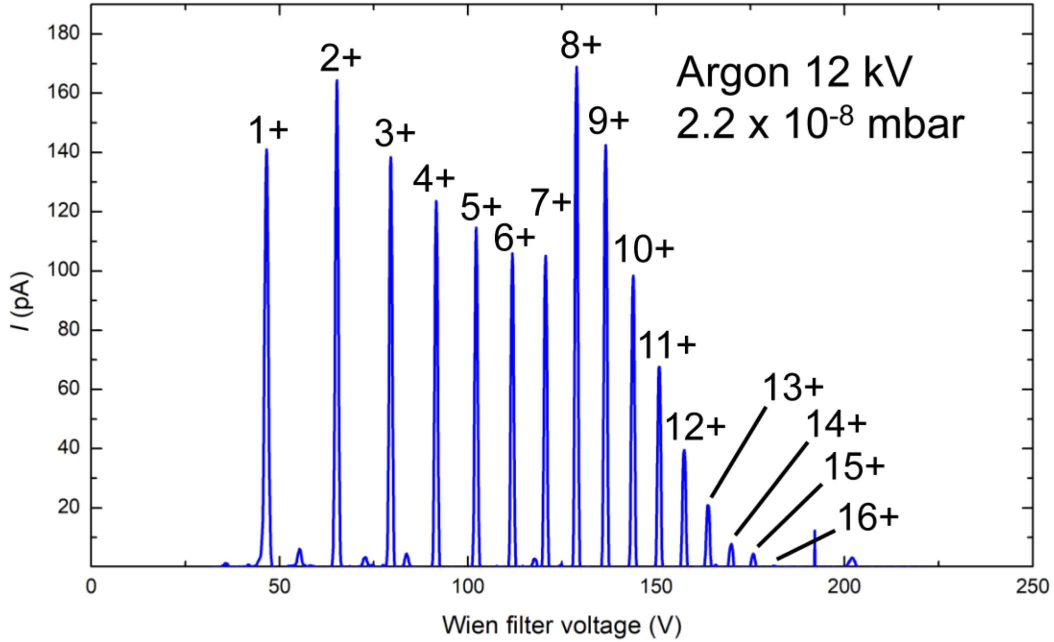


7 pA He, E = 11.5 keV

Experimental Results

SEM imaging





- SEM image captured with Ar^{8+} , I_{ion}=3 pA, U_0=12 kV, 80µm aperture
- Beam width: ≈ 1 µm
- Credit: Leibniz Joint Lab Single Ion Implantation

Experimental Results

Beam Quality

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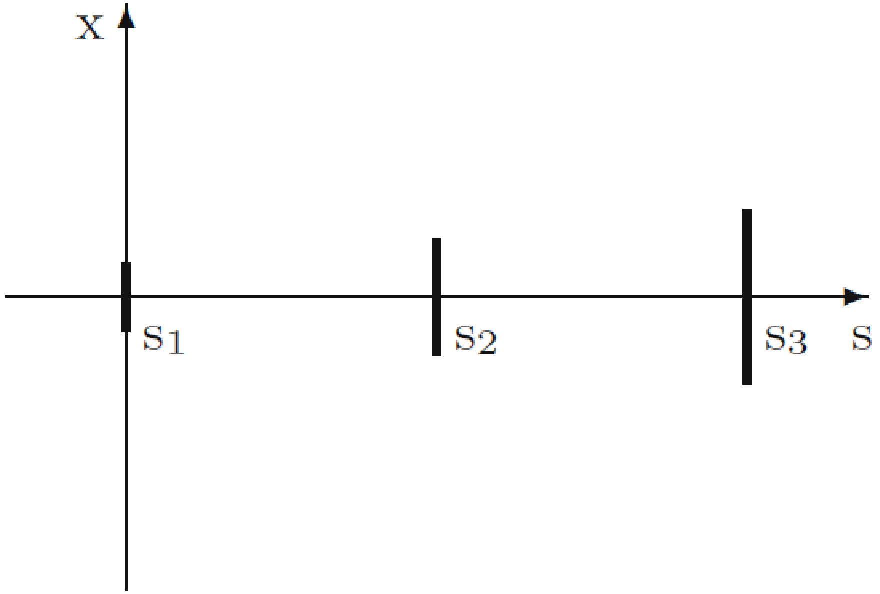
- Emittance derived from the beam width evolution in field free space
- Measurement method described in "F. Hinterberger, Physik der Teilchenbeschleuniger und Ionenoptik"
- Three beam width measurements at three different points required to calculate the sigma matrix
- Emittance measured in target chamber:

$$\varepsilon \sim 1 \text{ mm mrad}$$

- High beam quality makes EBIS suitable for ion optical elements with a low acceptance



* *F. Hinterberger, Physik der Teilchenbeschleuniger und Ionenoptik, 2008, Springer-Verlag Berlin Heidelberg*

Outlook

- Determination of ultimate minimum beam width (integral and charge state separated)
- Combination of SEM imaging and surface analysis via ToF-SIMS

Thank you for your attention

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