Precise Ion and Electron Beam Processing for Nano-Structuring

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IMS Nanofabrication GmbH

Vienna, Austria

Outline

- Short Introduction to IMS
- Technology Introduction
  - History of Ion and Electron Beam Structuring
  - Interaction with of Particles with Matter and Instrumentation
- Application Overview
- Challenges and Demands
  - Resolution
  - Productivity

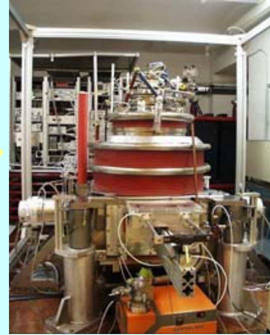
One possible solution:

- IMS Large Field Projection Optics
  - Projection Mask Less Lithography (PML2)
  - Projection Focused Ion multi-Beam (PROFIB)

Introduction to IMS

Austrian SME

„Think-Tank“ with hands-on experience

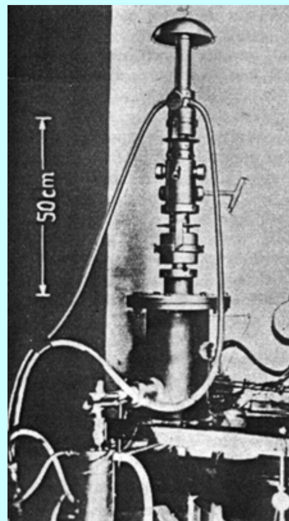


IMS Platform Technology
for
Micro- and Nanofabrication

History of Electron Beam Structuring

1931:
First EM (TEM) by Ernst Ruska

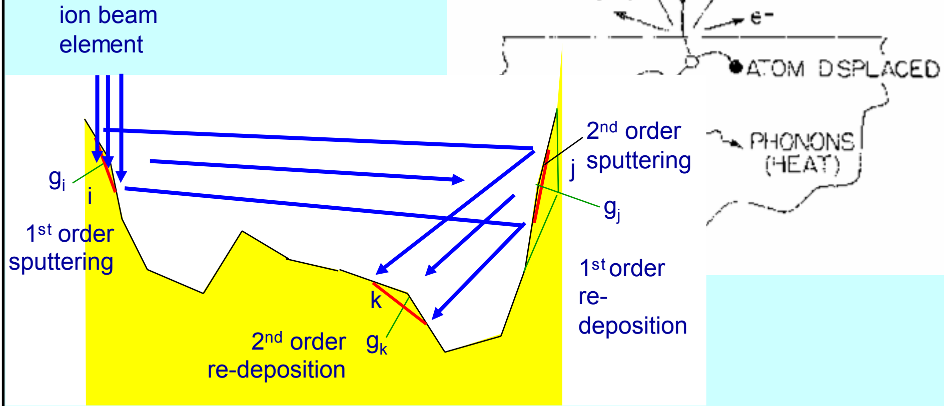
Nobel prize: 1986



Principles of Ion Beam Interactions

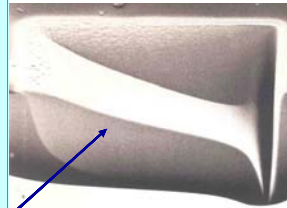
IonShaper Simulation Program:
Elmar Platzgummer (IMS Nanofabrication),
Alfred Biedermann (TU Vienna)

Source: John Melngailis,
J.Vac.Sci.Technol.B5(2), 469, Mar/Apr 1987



Principles of Ion Beam Interactions

Experiment: parallel FIB line scans
(Emmerich Bertagnolli, Alois Lugstein,
TU Vienna)



IonShaper Simulation Program:
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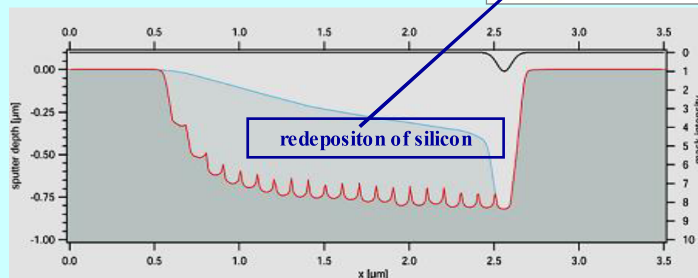
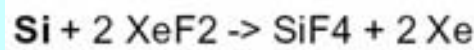
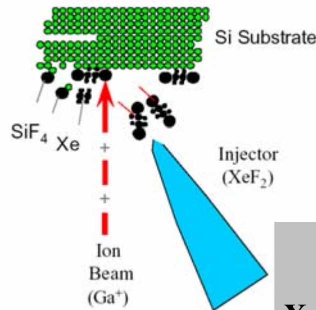


Principles of Ion Beam Interactions





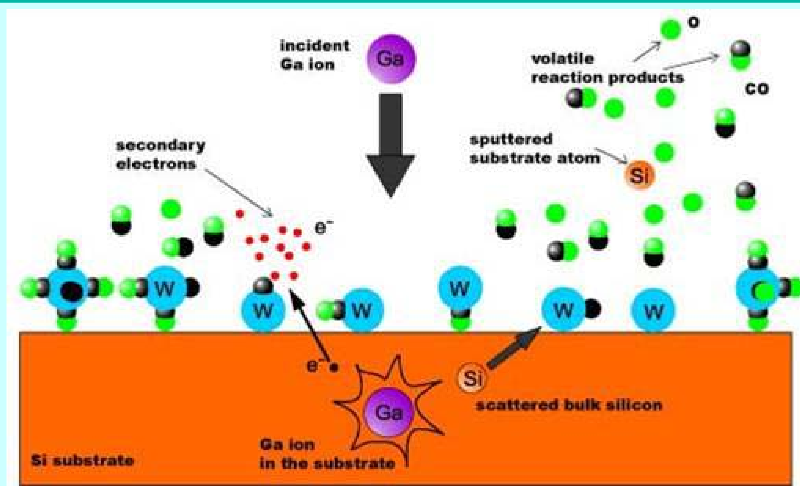
Source: FIB Folder TU Berlin,
Institut für Hochfrequenz und Halbleitertechnologien

Gas Enhancement Factors:

The enhancement factor indicate the removal efficiency of the FIB process with etchant gas relative to ion sputtering without etchant

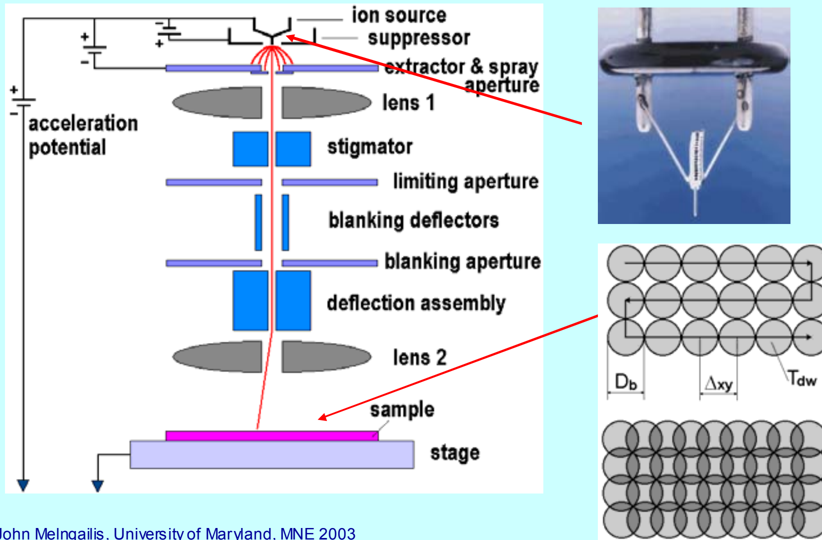
	SiO_2	Si_3N_4	Al	W	Si
XeF_2	10	8	-	6	>100
Cl_2	-	-	15	-	7
Br_2			15		6
H_2O	-	-	-	-	-

Principles of Ion Beam Interactions



Courtesy: Helmut Langfischer

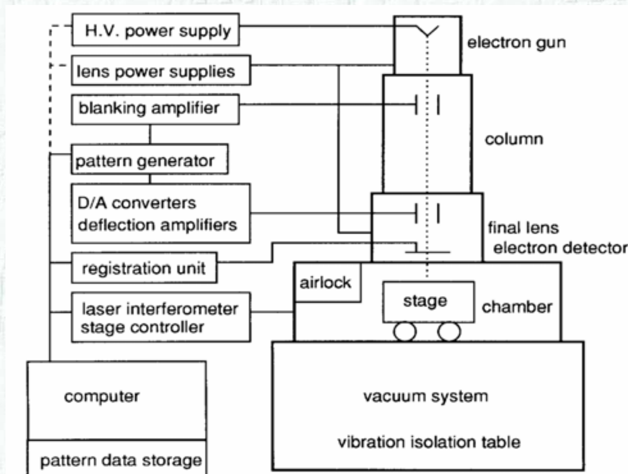
Principles of Instrumentation



Source: John Melngailis, University of Maryland, MNE 2003

Technical setup of EBL tools

E-beam tool concepts



Source: SPIE Handbook of Microlithography

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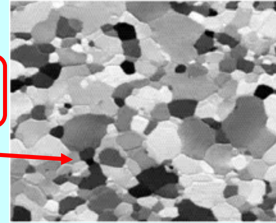
Application Overview (Selection)

Typical Industrial FIB Applications

Courtesy: Zeiss NTS & RAITH



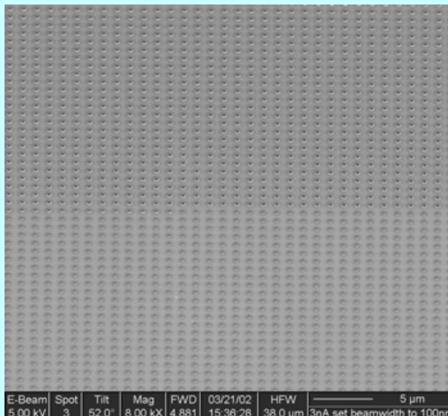
- Mask repair : defect removal & modification
- IC modification / Design edit: cut and paste operations
- SEM / TEM sample preparation: failure analysis
- Imaging & SIMS (visualizing of grain structures)
- Future: Hard disc heads

More todays Applications

- MST (prototype and development stage)
- Fabrication of scanning probe tips
- Micro Lenses and Mirrors (Aspherics)
- Nano Science and Technology !

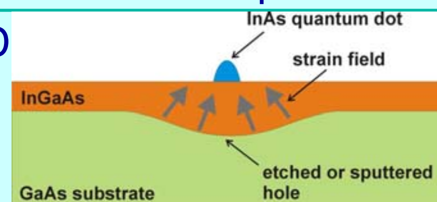
Nanotechnology Application: Examples

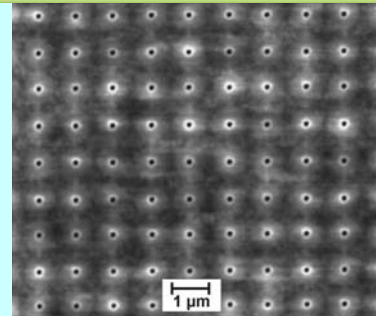
Photonic Array



Courtesy: FEI Company

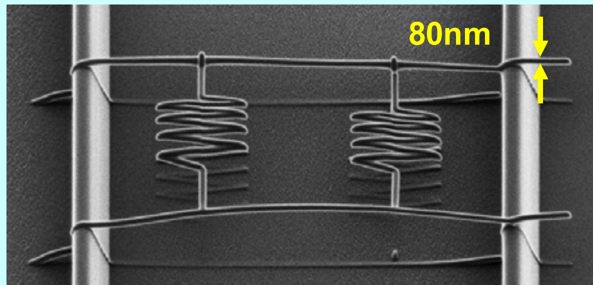
QD





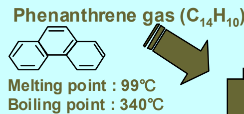
Courtesy: Gottfried Strasser

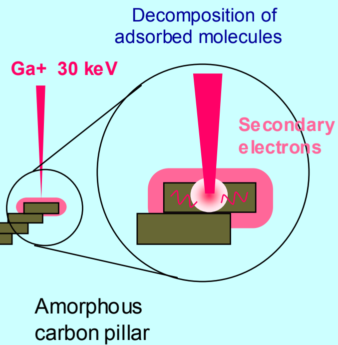
Nanotechnology Application: Example



Nano Air Wires

Parallel Resistance Air-Wiring
Growth time : 2.8 min





Source: Shinji Matsui, Himeji Institute of Technology, MNE 2003

Challenges and Demands

Talk at the MNE 2003, John Melngailis:

Nanofabrication Challenges

- milling at finer dimensions
  (lower energy beams, different ion species)
- ion induced deposition at finer dimensions,
  understanding deposition mechanisms
- developing novel fabrication techniques,

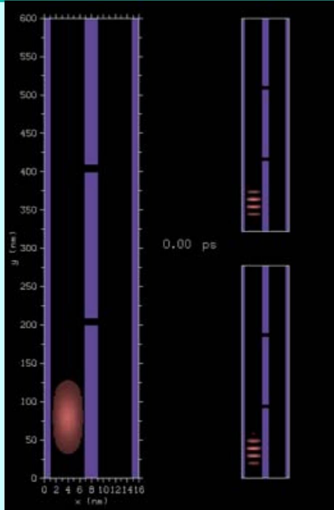
Source: John Melngailis, University of Maryland, MNE 2003

PRODUCTIVITY

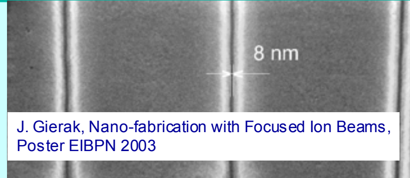
Examples:

- Quantum Computing
- Nano Imprint Stamps
- Optical Components

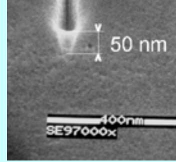
Quantum Computing: Demands < 10nm

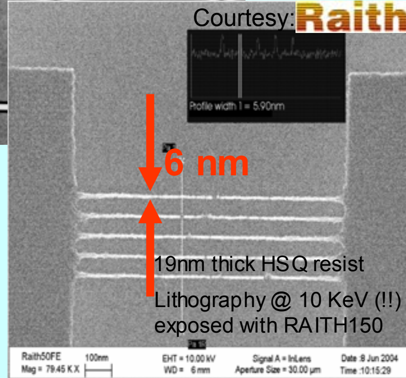


Courtesy: INMF Modena; Andrea Bertoni et al, Journal of Modern Optics, 2002, vol. 49, no. 8, 1219±1234

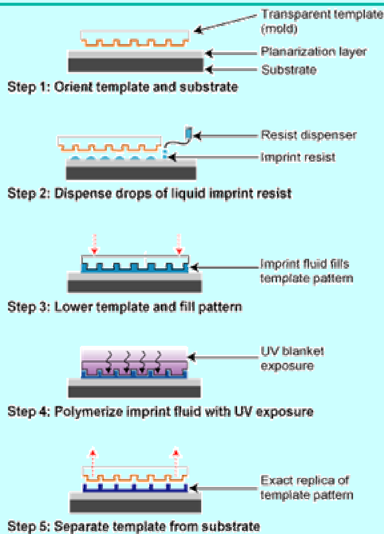


J. Gierak, Nano-fabrication with Focused Ion Beams, Poster EIBPN 2003



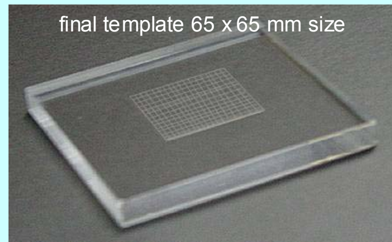


Fabrication of Nano Imprint Templates



www.smt.zeiss.com

Standard 6-inch x 6-inch x 0.250-inch fused silica blank

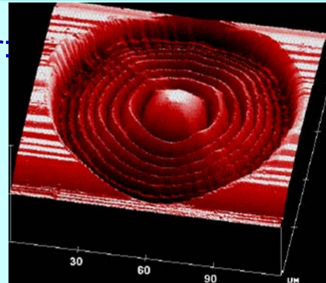


www.molecularimprints.com

Template fabrication process, typically accomplished with an e-beam writer, limits the resolution of the features.

Optical Components: DOE, Fresnel Lenses

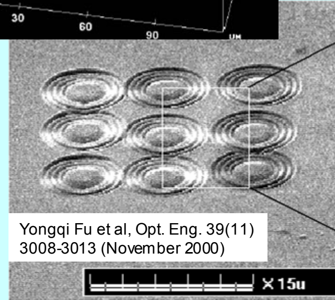
Optical Component Market Sector:



Realistic market of a few $ 100 million increasing to, perhaps $ 300 million by 2005

Nexus Market Analysis for Microsystems, 2002

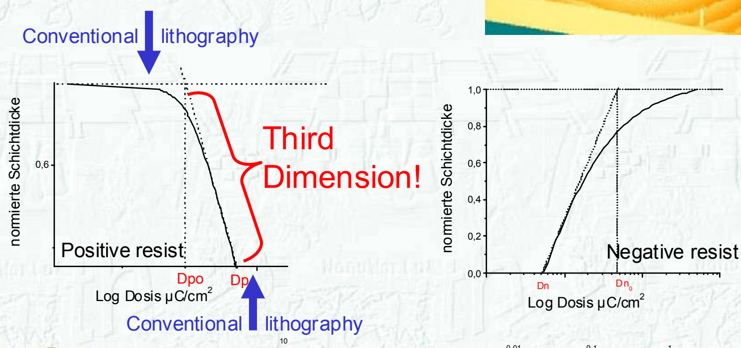
e.g.: Micro Lenses and Lens Arrays for focussing and / or redirection optical beams: Maximise optical coupling between (laser) sources and fibre or between input and output fibres of optical switch



E-beam lithography and fabrication process

Resists - 3Dimensional Lithography

Gradation Curve Contrast



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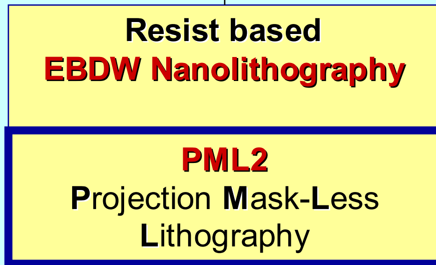
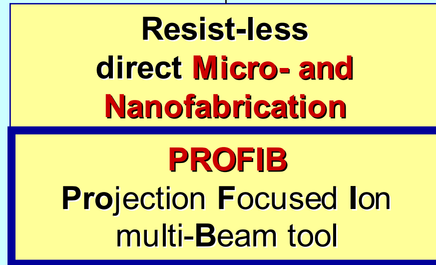
Introduction to IMS

IMS Platform Technology
for
Micro- and Nanofabrication

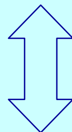




Large-Field Particle-Beam Optics

@ 200xReduction

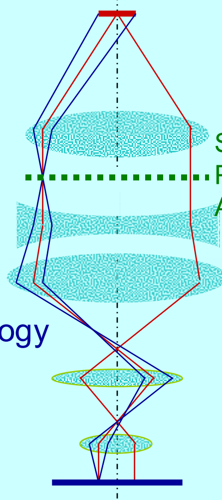
20 µm – 1 mm



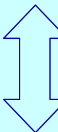
0.1 µm – 5 µm

Micro Systems Technology

SC Analytics,
Sensors, Lab-on-Chip, etc.



1 µm – 20 µm

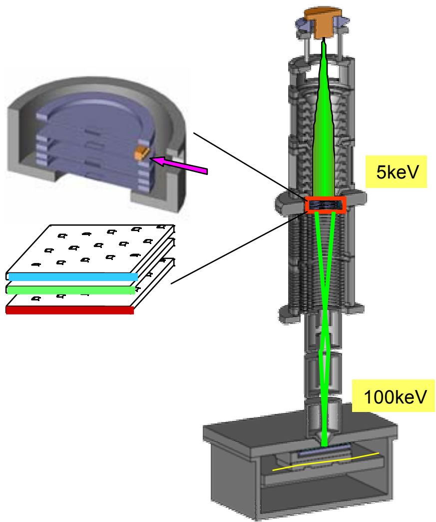


10 – 100nm

Nanotechnology

Nanoelectronics, Nanophotonics,
BioNanoTechnology, etc.

PML2 Multi e-beam, single column



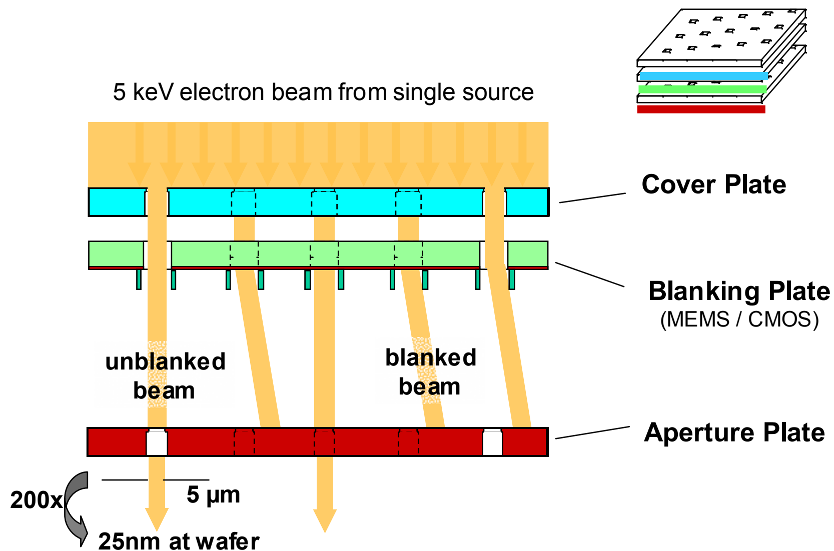
Single Electron source

Low beam energy at
Programmable Aperture Plate System (APS)

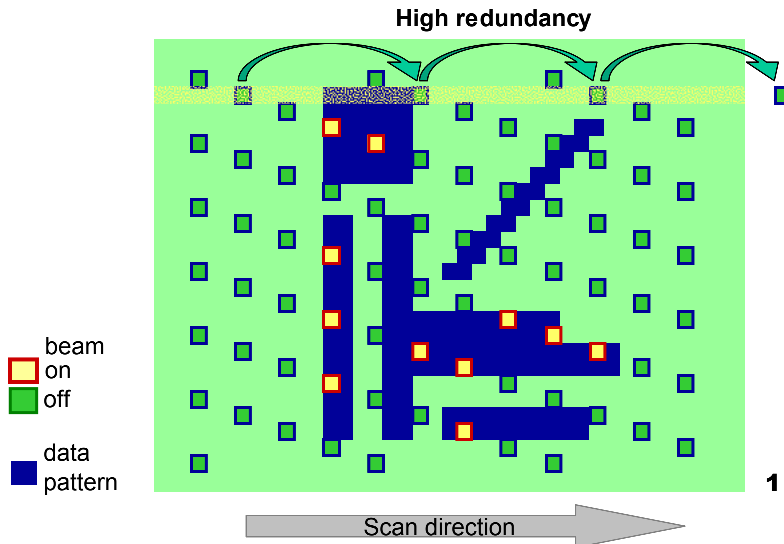
200x reduction projection optics with 2 cross overs

Scanning Wafer Stage

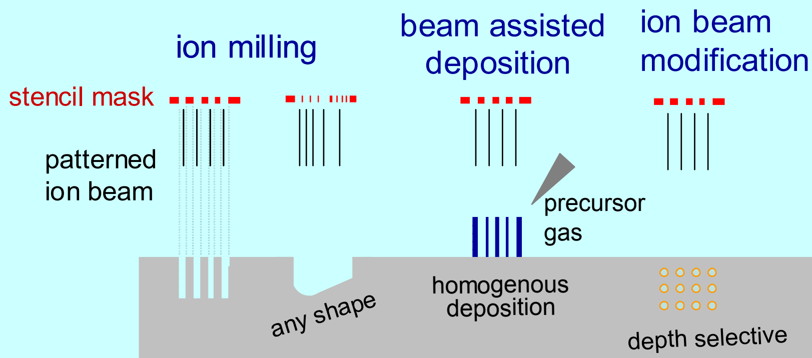
PML2 Dynamic Pattern Generation



PML2 Stepwise Exposure



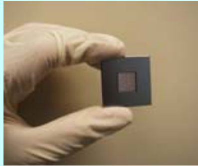
Projection Focused Ion multi-Beam (PROFIB)



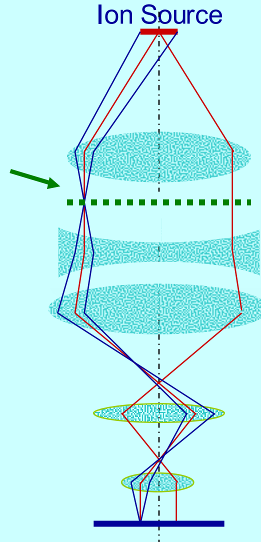
ion species: H+, He+, Ar+, Xe+,…
resolution: 10nm
exposure field: 25 µm x 25 µm

1 million 10nm dots per second (~ 10^{16} ions/cm²)

Projection Focused Ion multi-Beam (PROFIB)



Mask Plate



2 µm
mask plate
opening width

200x
reduction

10 nm
resolution, at
> 1nA
total ion beam
current at substrate

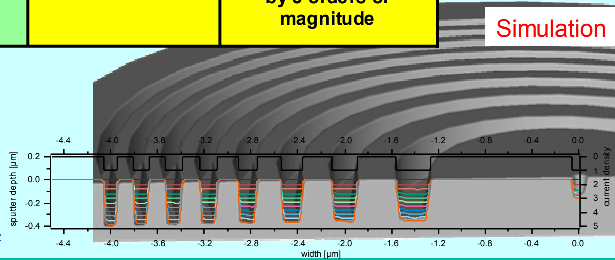
PROFIB Target Specs

Parameter	Specification
Working Envelope	150 mm diameter; 10 mm thickness
Image Field	40 µm diameter (25µm x 25µm)
Resolution @ 1nA total Ar+ ion beam current	10 nm
Surface roughness	< 5 nm, depending on material and feature depth
Feature Shape	adjustable shape, aspect ratio 2-3 for sputtering or 10-20 for reactive etching or deposition
Etching Rate	10 - 100 nm/s
Removal Rate	25 – 250 µm³/s
Types of Materials	silicon, metals, ceramics, glass, compounds, …

Projection Focused Ion multi-Beam (PROFIB)

	FIB	PROFIB	
Ion Beam Species	Ga^+	H^+, He^+, Ar^+, Xe^+,..	
Ion Beam **Current Density**	**~ A/cm²**	**~ mA/cm²**	advantage for gas assisted etching or deposition
total Ion Beam **Current** at Substrate	**~ pA**	**~ nA**	**higher productivity by 3 orders of magnitude**

FIB compared to PROFIB @ 10nm Resolution



Fresnel Zone Plate
Sputtertime: 30 s
Current Density: 0,1nA/µm²

Acknowledgements

Andrea Bertoni, University of Modena

Albert Biedermann, Vienna University of Technology

FEI Company

Kleindiek Nanotechnik

RAITH GmbH

Gottfried Strasser, Vienna University of Technology

Bernd Volbert, Namitec

Carl Zeiss SMT

Carl Zeiss NTS (former LEO)

and IMS collegues:
Christoph Brandstaetter, Stefan Cernusca, Marco Kuemmel,
Helmut Langfischer and Thomas Narzt