Precise Ion and Electron Beam Processing for Nano-Structuring

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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

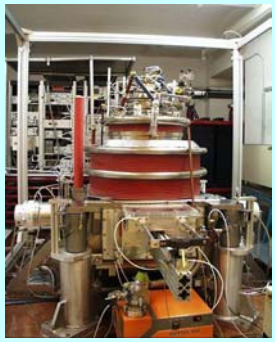
One possible solution:

- 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

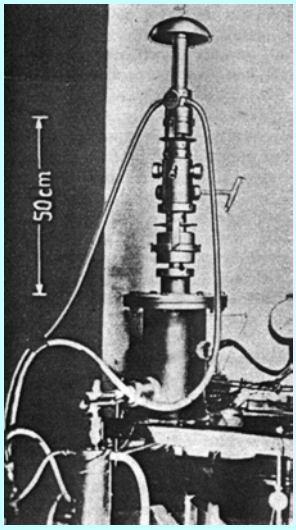


IMS Platform Technology
for
Micro- and Nanofabrication

History of Electron Beam Structuring

1931:
First EM (TEM) by Ernst Ruska

Nobel prize: 1986

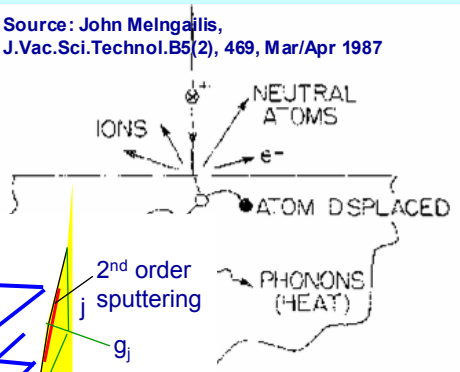


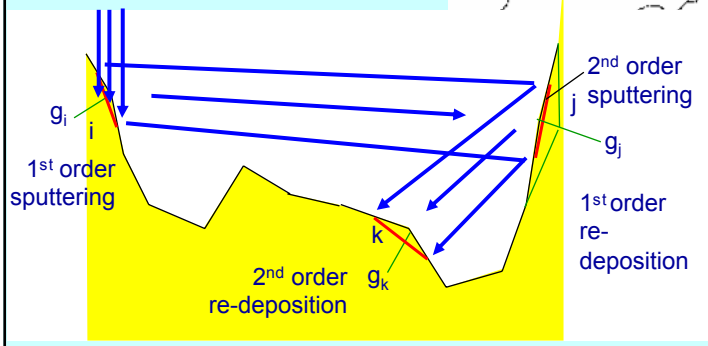
Principles of Ion Beam Interactions

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

ion beam element

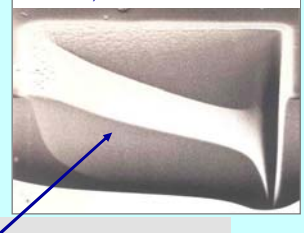
Source: John Melngailis, J.Vac.Sci.Technol.B5(2), 469, Mar/Apr 1987





Principles of Ion Beam Interactions

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



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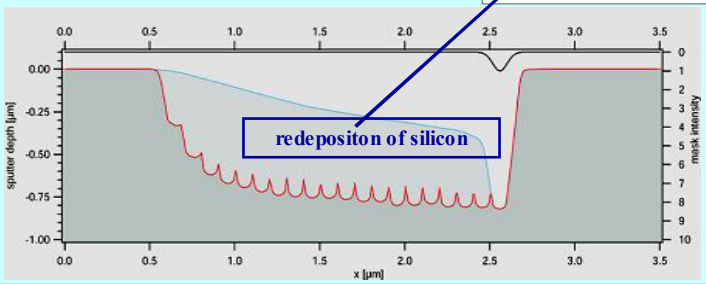
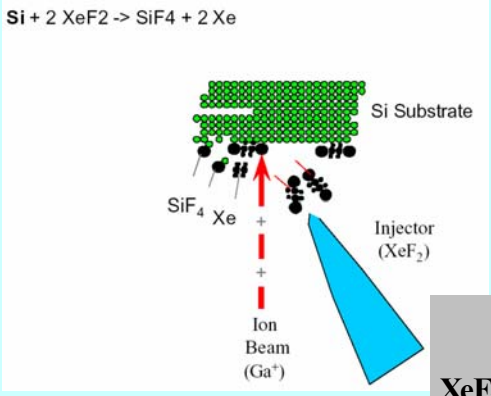


Principles of Ion Beam Interactions



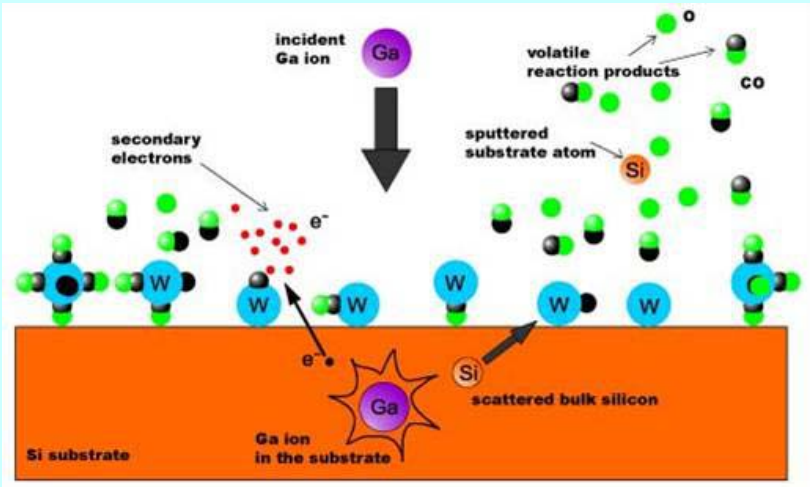
Source: FIB Folder TU Berlin,
Institut für Hochfrequenz und Halbleitertechnologien

Gas Enhancement Factors:

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

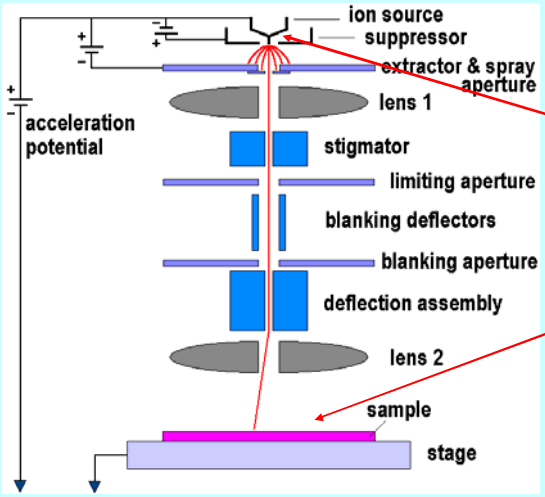
	SiO_2	Si_3N_4	Al	W	Si
XeF_2	10	8	-	6	>100
Cl_2	-	-	15	-	7
Br_2			15		6
H_2O	-	-	-	-	-

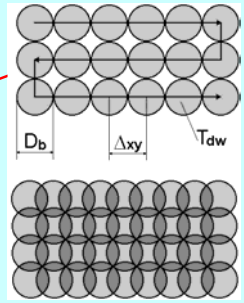
Principles of Ion Beam Interactions



Courtesy: Helmut Langfischer

Principles of Instrumentation

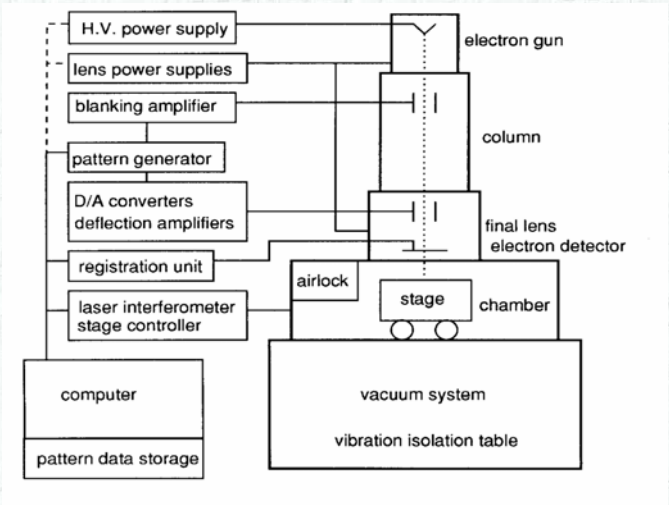




Source: John Melngailis, University of Maryland, MNE 2003

E-beam tool concepts

Technical setup of EBL tools



Source: SPIE Handbook of Microlithography

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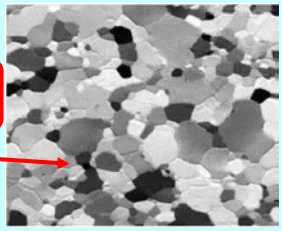
Application Overview (Selection)

Typical Industrial FIB Applications

Courtesy: Zeiss NTS & RAITH



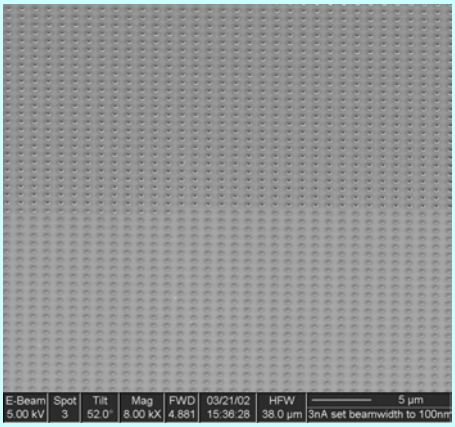
- Mask repair : defect removal & modification
- IC modification / Design edit: cut and paste operations
- SEM / TEM sample preparation: failure analysis
- Imaging & SIMS (visualizing of grain structures)
- Future: Hard disc heads

More todays Applications

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

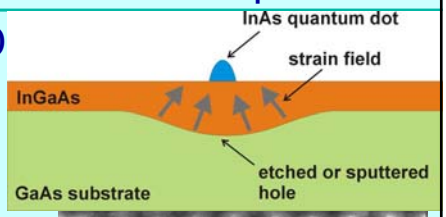
Nanotechnology Application: Examples

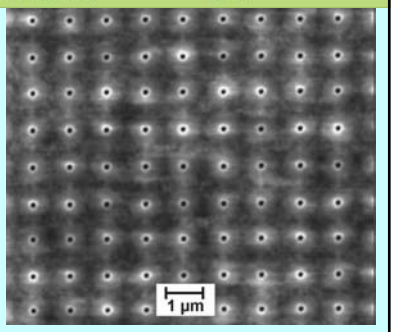
Photonic Array



Courtesy: FEI Company

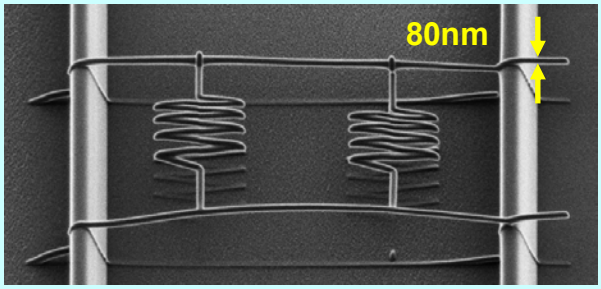
QD





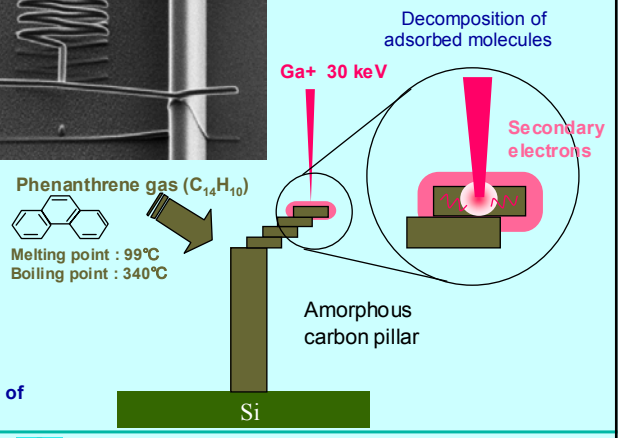
Courtesy: Gottfried Strasser

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,

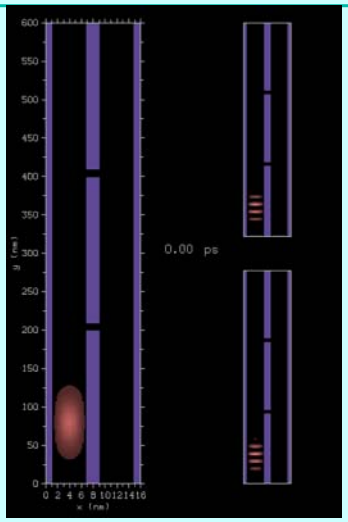
Source: John Melngailis, University of Maryland, MNE 2003

PRODUCTIVITY

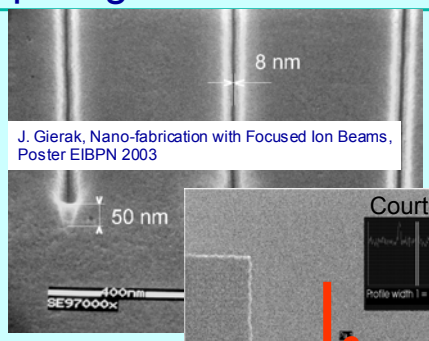
Examples:

- Quantum Computing
- Nano Imprint Stamps
- Optical Components

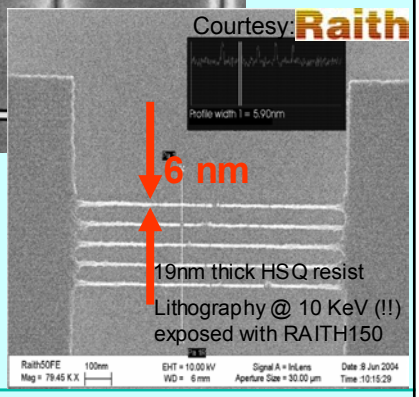
Quantum Computing: Demands < 10nm



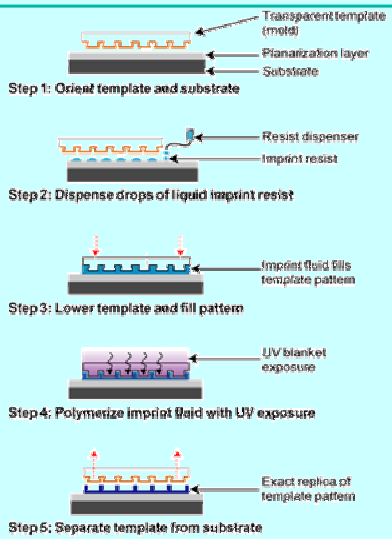
Courtesy: INMF Modena; Andrea Bertoni et al, Journal of Modern Optics, 2002, vol. 49, no. 8, 1219±1234



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

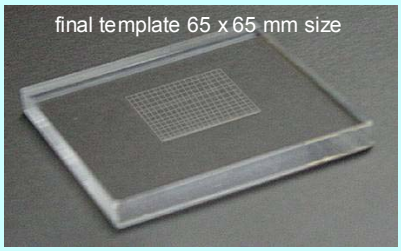


Fabrication of Nano Imprint Templates



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.

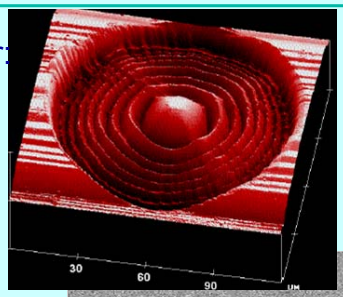
Optical Components: DOE, Fresnel Lenses

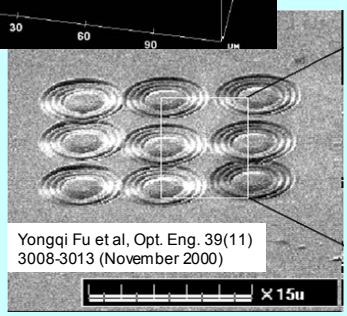
Optical Component Market Sector:

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

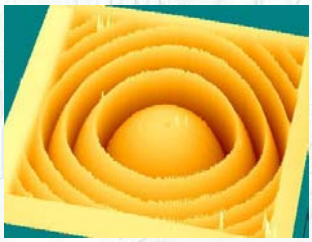


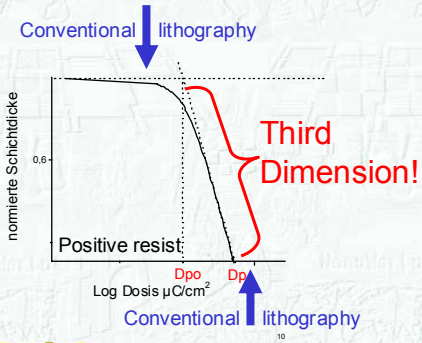


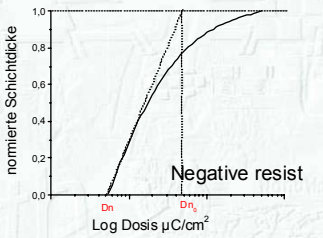
Resists - 3Dimensional Lithography

E-beam lithography and fabrication process

Gradation Curve
Contrast







Raith

Introduction to IMS

IMS Platform Technology
for
Micro- and Nanofabrication

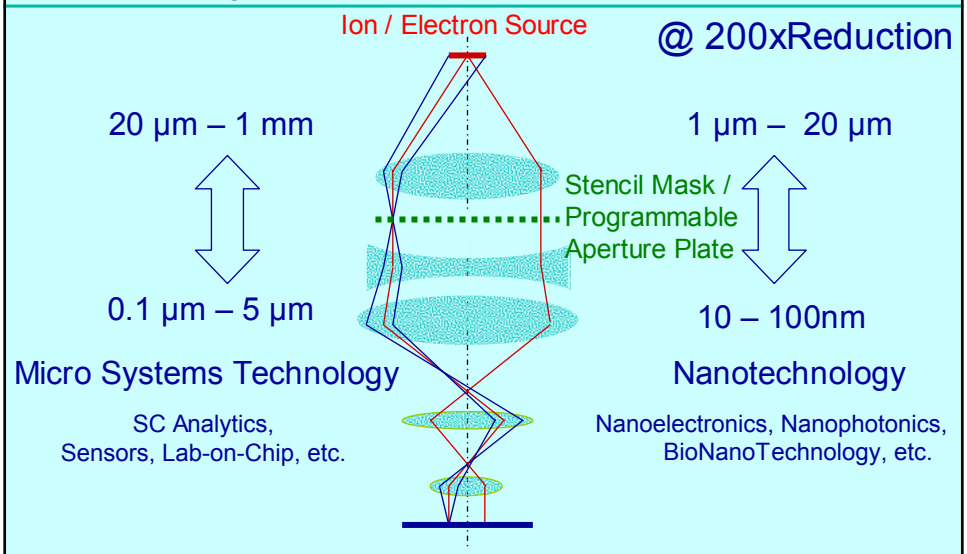
Resist based
EBDW Nanolithography

PML2
Projection **M**ask-**L**ess
Lithography

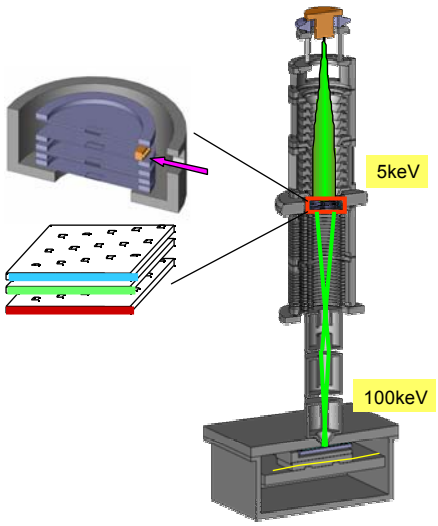
Resist-less
direct Micro- and Nanofabrication

PROFIB
Projection **F**ocused **I**on
multi-**B**eam tool

Large-Field Particle-Beam Optics



PML2 Multi e-beam, single column



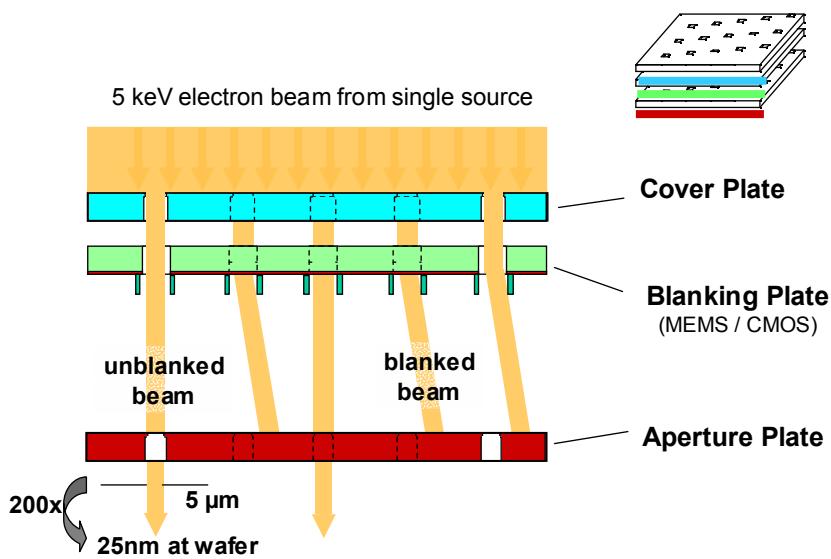
Single Electron source

Low beam energy at **Programmable Aperture Plate System (APS)**

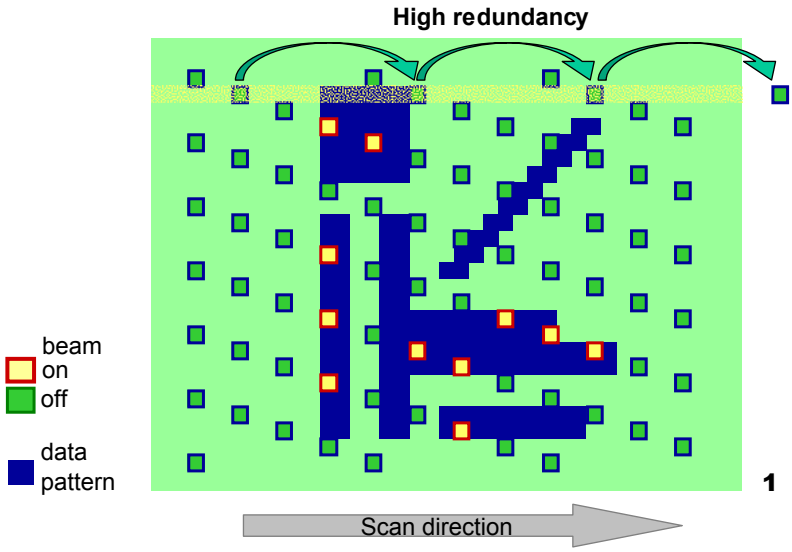
200x reduction projection optics with 2 cross overs

Scanning Wafer Stage

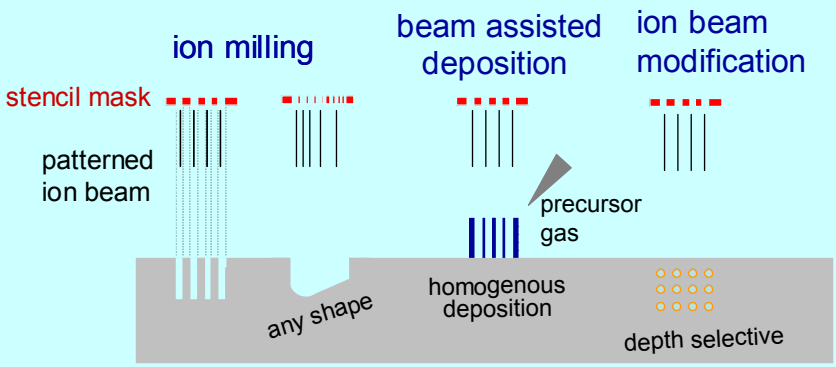
PML2 Dynamic Pattern Generation



PML2 Stepwise Exposure



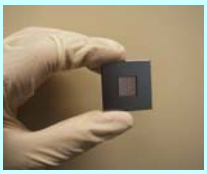
Projection Focused Ion multi-Beam (PROFIB)



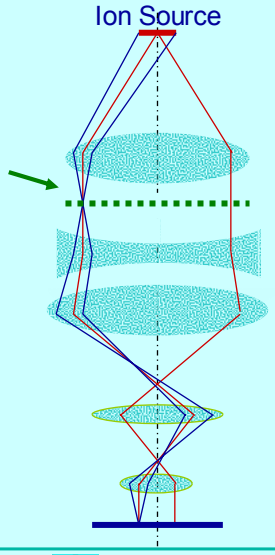
ion species:	H+, He+, Ar+, Xe+,…
resolution:	10nm
exposure field:	25 µm x 25 µm

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

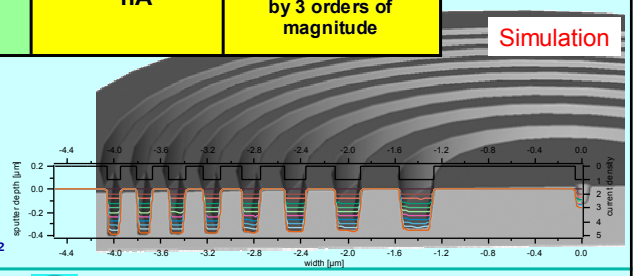
PROFIB Target Specs

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

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FEI Company

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Bernd Volbert, Namitec

Carl Zeiss SMT

Carl Zeiss NTS (former LEO)

and IMS collegues:
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Helmut Langfischer and Thomas Narzt