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)

1st order sputtering

2nd order re-deposition

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

redemption of silicon
Principles of Ion Beam Interactions

**Gas Enhancement Factors:**
The enhancement factor indicate the removal efficiency of the FIB process with etchant gas relative to ion sputtering without etchant.

<table>
<thead>
<tr>
<th></th>
<th>SiO₂</th>
<th>Si₃N₄</th>
<th>Al</th>
<th>W</th>
<th>Si</th>
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<tbody>
<tr>
<td>XeF₂</td>
<td>10</td>
<td>8</td>
<td>-</td>
<td>6</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Cl₂</td>
<td>-</td>
<td>-</td>
<td>15</td>
<td>-</td>
<td>7</td>
</tr>
<tr>
<td>Br₂</td>
<td></td>
<td>15</td>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>H₂O</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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

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
**Application Overview (Selection)**

### Typical Industrial FIB Applications

- 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!

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**Nanotechnology Application: Examples**

### Photonic Array QD

- InAs quantum dot strain field
- Etched or sputtered hole

**Courtesy:** FEI Company

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**QD**

**Courtesy:** Gottfried Strasser
**Nanotechnology Application: Example**

**Nano Air Wires**

- **Parallel Resistance Air-Wiring**
  - Growth time: 2.8 min

- **Phenanthrene gas (C_{14}H_{10})**
  - Melting point: 99°C
  - Boiling point: 340°C

- **Amorphous carbon pillar**

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

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**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

**Examples:**
- Quantum Computing
- Nano Imprint Stamps
- Optical Components

**Source:** John Melngailis, University of Maryland, MNE 2003
Quantum Computing: Demands < 10nm

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

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

Fabrication of Nano Imprint Templates

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.

www.molecularimprints.com
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

Gradation Curve

Contrast

Conventional lithography

Positive resist

Negative resist

E-beam lithography and fabrication process

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Introduction to IMS

IMS Platform Technology for Micro- and Nanofabrication

- Resist based EBDW Nanolithography
- Resist-less direct Micro- and Nanofabrication
- PML2 Projection Mask-Less Lithography
- PROFIB Projection Focused Ion multi-Beam tool

Large-Field Particle-Beam Optics

@ 200xReduction

- Ion / Electron Source
- 20 µm – 1 mm
- 0.1 µm – 5 µm
- 1 µm – 20 µm
- 10 – 100nm

Micro Systems Technology

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

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

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**PML2** Dynamic Pattern Generation

- 5 keV electron beam from single source
  - **Cover Plate**
  - **Blanking Plate** (MEMS / CMOS)
  - **Aperture Plate**
- 200x reduction
- 5 µm
- 25 nm at wafer
**PML2**

**Stepwise Exposure**

High redundancy

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**Projection Focused Ion multi-Beam (PROFIB)**

- **ion milling**
  - stencil mask
  - patterned ion beam
- **beam assisted deposition**
- **ion beam modification**
  - precursor gas
  - homogenous deposition
  - depth selective

**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)

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IMS Nanofabrication GmbH

EFUG 2004, EMPA Akademie, Oct 4, 2004
Projection Focused Ion multi-Beam (PROFIB)

**PROFIB Target Specs**

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

<table>
<thead>
<tr>
<th>FIB</th>
<th>PROFIB</th>
</tr>
</thead>
</table>
| Ion Beam Species | Ga⁺, H⁺, He⁺, Ar⁺, Xe⁺, ...
| Ion Beam Current Density | ~ A/cm², ~ mA/cm² |
| Advantages | higher productivity by 3 orders of magnitude |

- Simulation
- Fresnel Zone Plate
- Sputter time: 30 s
- Current Density: 0.1 nA/µm²
- Profib @ 10 nm

Resolution

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Carl Zeiss NTS (former LEO)

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