Economics of Mask

October 3, 2023
Glen Scheid, Operations Manager
Mask Technology Center
Micron Technology Inc.
Examination of the photomask economy

1. Capital
2. Materials
3. Software

Micron’s Mask Technology Center perspective

Future Considerations
BACUS Webinar: Overview of Photomask Technology
Glen Scheid of Micron gives an overview of Photomask Technology.
Hosted by Doug Resnick of Canon Nanotechnologies Inc.

Register now
Transforming how the world uses information to enrich life for all

- Engaged Team Members
- Leading Edge Products
- Responsible Operations

Founded on October 5, 1978

Headquartered in Boise, Idaho USA

- Photomask Manufacturing Sites
- Frontend Manufacturing Sites
- Assembly & Test Manufacturing Sites
- Micron Offices

Assembly & Test Manufacturing Sites:
- United States
- Canada
- Mexico
- Taiwan
- Malaysia
- South Korea
- Japan
- Singapore
- Europe
- India
- China
- Europe

Micron Offices:
- United States
- Canada
- Mexico
- Taiwan
- Singapore
- Europe
- India
- China
- South Korea
- Japan
EUV mask costs may be as much as 30x optical with equivalent lifetime.
Increasing Cost of Ownership

**Capital & Service Cost vs. Throughput:**

- Complex optics and multi-beam arrays
- EUV light generation source
- Specialized labor

**Facility Space:**

- Larger EUV source systems
- Vacuum chambers
- Support equipment
**Longer Equipment Lead Times**

**Baseline Equipment Causes:**
- Macro-economic factors
- Supply chain quality
- Supply and demand

**EUV Equipment Additional Causes:**
- Complex technologies
- Limited supply chain
- Supply chain bottlenecks

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**Relative Lead Time**

- **CD SEM**
  - FOAK 2018
  - SOAK 2023

- **Registration**
  - FOAK 2019
  - SOAK 2023

- **Inspection**
  - FOAK 2019
  - SOAK 2023

- **Printability Simulation**
  - FOAK 2019
  - SOAK 2023
Creating State-of-the-Art Through Partnership

**Hardware**
- Capability aligned to the market
- Risk reduction for supplier
- Cost reduction for mask maker

**Software**
- Cloud based MPC and MDP

**Materials**
- Customer specific innovations
- ASML TNO qualifications

**Protected IP sharing**
- Third-party cloud providers
Wafer fab reticle equipment demands

Mask equipment in the wafer fab is required for EUV reticle management:

- Cleaning
- Inspection
- Particle removal / analysis
- Pod-in-Pod cleaning
- Stockers / cabinets
- Pellicle support

Micron’s expansion is adding mask equipment, software, and materials around the world.
Cost of Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Optical</th>
<th>EUV</th>
</tr>
</thead>
<tbody>
<tr>
<td>blanks</td>
<td>![Bar Chart]</td>
<td>![Bar Chart]</td>
</tr>
<tr>
<td>optical EUV</td>
<td><strong>$100,000.</strong> [Source: semiengineering.com]</td>
<td></td>
</tr>
</tbody>
</table>

“An EUV mask blank with tighter specs can cost more than $100,000.”

<table>
<thead>
<tr>
<th>Material</th>
<th>Optical</th>
<th>EUV</th>
</tr>
</thead>
<tbody>
<tr>
<td>resist</td>
<td>![Bar Chart]</td>
<td>![Bar Chart]</td>
</tr>
<tr>
<td>optical EUV</td>
<td><strong>Low sensitivity resists using advanced polymers, PAG and specialty components required for EUV.</strong></td>
<td></td>
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</tbody>
</table>

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<thead>
<tr>
<th>Material</th>
<th>Optical</th>
<th>EUV</th>
</tr>
</thead>
<tbody>
<tr>
<td>pellicles</td>
<td>![Bar Chart]</td>
<td>![Bar Chart]</td>
</tr>
<tr>
<td>optical EUV</td>
<td><strong>...pellicle themselves are also very expensive, in the tens of millions of won...</strong> [tens of thousands of dollars] [Source: ELEC]</td>
<td></td>
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</table>

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<thead>
<tr>
<th>Material</th>
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<tbody>
<tr>
<td>pods</td>
<td>![Bar Chart]</td>
<td>![Bar Chart]</td>
</tr>
<tr>
<td>optical EUV</td>
<td>![Image]</td>
<td>![Image]</td>
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<tr>
<td>Considerations with Pellicle</td>
<td>Considerations without Pellicle</td>
<td></td>
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<tr>
<td>-----------------------------</td>
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<td></td>
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<tr>
<td>Pellicle unit costs, inventory space, and labor.</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Pellicle lifetime, replacement costs.</td>
<td></td>
<td></td>
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<tr>
<td>Pellicle compatible pods</td>
<td></td>
<td></td>
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<tr>
<td>Pellicle equipment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• MDR (mount-demount-remount)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Transmission, Inspection, particle analysis, and removal.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mask</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Periodic inspection, potentially using APMI.</td>
<td>Higher risk of defectivity, repairs required.</td>
<td></td>
</tr>
<tr>
<td>Longer lifetimes due to less frequent cleaning.</td>
<td>Less mask productive time.</td>
<td></td>
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<tr>
<td>Small reduction in aerial CD uniformity.</td>
<td>More backup masks.</td>
<td></td>
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<tr>
<td>Less frequent requirement for mask defect management.</td>
<td>More frequent mask defect management / capital eq.</td>
<td></td>
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<tr>
<td>Scanner</td>
<td></td>
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<tr>
<td>Downtime due to damaged pells.</td>
<td>Downtime due to scanner actions in response to mask defects.</td>
<td></td>
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<tr>
<td>Throughput loss due to transmission including addition of DGL membrane</td>
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</table>
EUV Handling Creates Significant Infrastructure

Automatic Reticle Transportation

- Quality Control
- Labor reduction
- Pod Management
- Host & Scheduling

Pod Stocker
Pod Cabinets
Pod Washer
Pod Inspection (option)
Pod Inspection ADC (option)

Actual implementation
Mask Shop Specific Software

Photomask specific software tools, further motivated by EUV, is enabling advanced analytics in the mask shop.

Building blocks of an effective DMS architecture
Need for comprehensive reticle data management and analytics: BACUS 2020, Micron & KLA

Production flow for EUV defect avoidance using KlearView database and blank defect optimize (BDO)
Comprehensive extreme ultraviolet blank defect avoidance system: BACUS 2022, Micron & KLA

SEM ADC workflow
Classification and printability of EUV mask defects from SEM images: BACUS 2017, Micron & KLA
Future considerations

High NA / Hyper NA EUV

• Expected further evolution of the photomask infrastructure already in place.
• Considerations of an alternative mask size can create significant capital and facility cost impact.

Continued pricing pressure

• High-end materials and equipment required to meet next generation specifications will likely create new cost challenges.

Software

• Expanded focus on data security to protect IP with increased data sharing.
• Increased use of deep learning/AI/data science tools within mask shops to maximize efficiencies and improve capabilities.
Thank you for listening!

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