Advanced Deposition Techniques For Next Generation EUV Mask Blanks

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Current EUV Mask Blank Structure

Absorber: TaN
Cap: Ru
Mirror: 40x Mo/Si
Backside coating: CrN

Backside (CrN)  | Substrate  | Mirror (40X Mo/Si)  | Cap (Ru)  | Absorber (TaN)
--- | --- | --- | --- | ---
Resistivity  | Defects  | Defectivity  | Thickness  | Defects
Coeff of friction  | Roughness  | CWL, Reflectivity  | Durability  | Reflectivity
Hardness  | CTE  | Non uniformity  | Reliability  | Non uniformity
Roughness  | PV, Bow  | FWHM  | Etch selectivity  | Thickness
Optical density  | Dimension  | Roughness  | Roughness  | Etch properties
Defects  |  | Interface mixing and roughness  |  | Cleaning reliability
Non uniformity  |  |  |  |  

TEM EUV Mask Blank Materials System
# Drivers for Next Generation EUV Mask Blank

<table>
<thead>
<tr>
<th>Key Drivers</th>
<th>Implication</th>
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</thead>
</table>
| **Absorber** | • Reduced thickness with Higher Absorption | • New Materials  
• New etch and clean chemistries |
| **Cap** | • Durability and Reliability  
• Integration with Thin Absorber | • New Materials  
• New etch and clean chemistries |
| **Mirror** | • Low Defectivity  
• Higher Reflectivity  
• Reduced NU | • Interface engineering |
| **Substrate** | • Low Defectivity  
• PV/Bow | • Polishing and clean control |
| **Backside** | • Hardness to improve durability maintaining $\mu$ and resistivity | • New Materials |

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**EUV Mask Blank Materials System**

*Precision materials engineering techniques needed for next generation EUV mask requirements*
Next Generation EUV Mask Blanks Requires Materials Innovation and Defect Control
Applied: Largest Set of Materials Engineering Capabilities

Applied’s Advanced Deposition Technologies Enables Custom Films Development to Address EUV Mask Drivers
Backside Coating Optimization

**Key Drivers**
- Hardness to improve durability maintaining $\mu$ and resistivity
- New Materials

**Implication**

<table>
<thead>
<tr>
<th>Benchmark test coating</th>
<th>Applied CrN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical load (mN)</td>
<td>392</td>
</tr>
<tr>
<td>CoF</td>
<td>&lt;0.25</td>
</tr>
<tr>
<td>Roughness</td>
<td>0.2 nm</td>
</tr>
<tr>
<td>Sheet resistance</td>
<td>&lt;50 ohm/sq</td>
</tr>
<tr>
<td>Scratch resistance</td>
<td>Meets / few scratches</td>
</tr>
</tbody>
</table>

**Defects during CrN deposition:** 0 @1um

- Optimized CrN performance using advanced deposition methods
- Investigating additional material systems for further improvement
Mirror Multi-Layer Optimization

**Key Drivers**
- Durability and Reliability
- Integration with Thin Absorber
- Low Defectivity
- Higher Reflectivity
- Reduced NU

**Implication**
- New Materials
- New etch and clean chemistries
- Interface engineering

**Cap**

**Mirror**

- Mo/Si Intermixing
- ~2nm silicide formation

- Sharp interface engineering with Applied’s deposition technology
- Sub-nm silicide formation

- Engineering interfaces to minimize intermixing and maximize reflectivity
Mirror Multi-Layer Optimization

**Key Drivers**
- Durability and Reliability
- Integration with Thin Absorber
- Low Defectivity
- Higher Reflectivity
- Reduced NU

**Implication**
- New Materials
- New etch and clean chemistries
- Interface engineering

- **Low Defectivity.** Dense Ru layer with no damage observed from Etching/Cleaning processes
- **Developing capping materials to address future Durability/Etching requirements**
TaN Absorber Benchmark

Defects during TaN deposition

- Need for advance absorber to reduce M3D effects
Advanced Absorber Development

**Key Attributes**

- n and k values which can provide less than 2% reflectivity for less than 45nm thickness on ML+Ru
- Single phase, amorphous & stable films
- Cleaning durability and etch-ability
- Good adhesion and etch selectivity with capping layer
- Operating temperature and hydrogen resistant
- Low surface roughness, Low or compensated stress, DUV contrast for inspection
- Repair

- Novel use of simulation methods and empirical materials library identified thin absorber candidates
- Optimized deposition techniques provide amorphous, low reflectance films

### Material System A

<table>
<thead>
<tr>
<th></th>
<th>ML</th>
<th>Absorber (A)</th>
<th>Beamline Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reflectivity</td>
<td>66.3%</td>
<td>66.5%</td>
<td>66.0%</td>
</tr>
<tr>
<td>CWL</td>
<td>13.54</td>
<td>13.54</td>
<td>13.52</td>
</tr>
<tr>
<td>Thickness (nm)</td>
<td>35</td>
<td>40</td>
<td>45</td>
</tr>
<tr>
<td>Reflectivity</td>
<td>3.5%</td>
<td>&lt;2%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Reflectivity</td>
<td>&lt;2%</td>
<td>&lt;2%</td>
<td></td>
</tr>
</tbody>
</table>
• Multiple other material systems exhibit amorphous single phase that provide less than 2% reflectivity for sub 45 nm thickness
• Etch compatibility validation is in progress
Tetra™ Z – EUV Features and Benefits

Chamber and Source RF Design
- Enhanced CDU control
- Wider Process Window

Advanced Cathode Design
- New Cathode/lift design for min contact
- Reduced backside etching
- Improved CDU
- Lower Defects

Next Generation Chamber Materials
- New chamber materials
- Lower defects

Recursive Multi-port Gas Injection
- Uniform Gas Injection Module
- Enhanced CDU Control

RF with Full Digital Control
- Fast tuning and improved striking/stability
- Advanced source and bias pulsing and control for wider process window
- RF stability and control independent of position

Advanced End Point Control
- State-of-the-art REP combined with OES and IEP technologies with advanced algorithms
- Absorber and black border ML etch
- Partial ML etch for EUV PSM applications

- Tetra™ Z EUV Chamber Developed and Used for Next generation EUV Mask Requirements
Next Generation EUV Mask Blanks Requires Integrated Solution for Customers
Applied’s Portfolio for EUV Masks

- Applied’s broad and deep photomask infrastructure and R&D capability offers unique ability to enable custom materials engineering and modifications to address customer’s problem
Summary

- Applied’s Advanced Deposition technologies can address future EUV mask requirements
- Using various materials engineering techniques, Applied has
  1. improved CrN backside properties,
  2. reduced the Mo/Si intermixing for the mirror layer,
  3. optimized the TaN layer,
  4. identified viable thin absorber materials,
  5. and continues to explore material systems at an accelerated pace.

- Next steps include validation of new material systems as an option for next generation EUV mask blanks
  - validation of etch-ability, cleaning durability, and imaging performance

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