Progress of EUV blanks development

Takahiro Onoue, Tsutomu Shoki, Jun-ichi Horikawa
HOYA Corporation
Blanks division
Outline

1. EUV blanks history and progress
   • HOYA development history
   • EUV focus area trend

2. EUV blanks development: current status
   • HOYA’s strength
   • Difficulties in EUV blanks
   • Current status

3. Summary
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1. EUV blanks history and progress
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   ● HOYA’s strength
   ● Difficulties in EUV blanks
   ● Current status

3. Summary
Mask Blank is considered as a high risk item for EUV Lithography.

*The same message shown by Hoya, at the 8th annual SEMATECH symposium in 2012.*
EUV Focus Areas 2006-2010: 22 nm half-pitch insertion target

<table>
<thead>
<tr>
<th>Year</th>
<th>2007 / 22hp</th>
<th>2008 / 22hp</th>
<th>2009 / 22hp</th>
<th>2010 / 22hp</th>
<th>2011 / 22hp</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Reliable high power source &amp; collector module</td>
<td>Long-term source operation with 100 W at IF and 5MJ/day</td>
<td>Mask yield &amp; defect inspection/review infrastructure</td>
<td>Mask yield &amp; defect inspection/review infrastructure</td>
<td>Long-term reliable source operation with 200 W at IF*</td>
</tr>
<tr>
<td>2.</td>
<td>Resist resolution, sensitivity &amp; LER met simultaneously</td>
<td>Defect free masks through lifecycle &amp; inspection/review infrastructure</td>
<td>Long-term reliable source operation with 200 W at IF</td>
<td>Mask yield &amp; defect inspection/review infrastructure</td>
<td>Mask yield &amp; defect inspection/review infrastructure</td>
</tr>
<tr>
<td>3.</td>
<td>Availability of defect free mask</td>
<td>Resist resolution, sensitivity &amp; LER met simultaneously</td>
<td>Resist resolution, sensitivity &amp; LER met simultaneously</td>
<td>Resist resolution, sensitivity &amp; LER met simultaneously</td>
<td>Resist resolution, sensitivity &amp; LER met simultaneously</td>
</tr>
<tr>
<td>4.</td>
<td>Reticle protection during storage, handling and use</td>
<td>Reticle protection during storage, handling and use</td>
<td>EUVL manufacturing integration</td>
<td>EUVL manufacturing integration</td>
<td>EUVL manufacturing integration</td>
</tr>
<tr>
<td>5.</td>
<td>Projection and illuminator optics quality &amp; lifetime</td>
<td>Projection / illuminator optics and mask lifetime</td>
<td></td>
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</tbody>
</table>

*) This requires a 20X improvement from current source power status

HVM introduction in late 2013 if productivity challenge can be met
# HOYA EUV Blanks Development History

**Current Phase: CY2012~**

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Exposure tool</td>
<td></td>
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<tr>
<td>EUV Activity In US</td>
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<tr>
<td>Japan EUV Program Mask Inspection</td>
<td></td>
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<tr>
<td>HOYA Defect Inspection</td>
<td></td>
<td></td>
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<tr>
<td>HOYA EUV blank</td>
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</tbody>
</table>

- **Exposure tool:**
  - ★MET
  - ★α tool
  - NXE Tool

- **EUV Activity In US:**
  - EUVLLC
  - SEMATECH

- **Japan EUV Program Mask Inspection:**
  - ASET
  - MIRAI
  - *Selete
  - *EIDEC: BI project
  - ABI in Selete and EIDEC

- **HOYA Defect Inspection:**
  - ABI Tool
  - Teron Phasur

- **HOYA EUV Blank Development:**
  - R&D
  - Proto line
  - Pilot line

- **Focusing on blank development with high sensitivity inspection toward EUVL production**

- **Fiducial mark:**
  - ★Ru_A
  - ★TaB-Back side

- **PDM for inspection:**
  - ★PDM for inspection

- **Teron Phasur:**
  - MIRAI

- **Selete:**
  - ◆ASET
  - ◆MIRAI

- **EIDEC:**
  - ◆BI project

- **TaBN ABS:**
  - ◆TaBN ABS

- **MET:**
  - ◆MET

- **α tool:**
  - ◆α tool

- **NXE Tool:**
  - ◆NXE Tool
• Defect level of EUV blanks has been greatly reduced over >5 years.
• Mask Blank is still considered as a high risk item for EUVL?
  ...Yes/No
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   - HOYA development history
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   - HOYA’s strength
   - Difficulties in EUV blanks
   - Current status

3. Summary
HOYA’s strength

• HOYA is the only blanks supplier that covers optical (ArF, KrF), EUV and FPD.
• We have continuing business especially for optical blanks for several decades. We will accelerate EUV blanks development using the infrastructure for 6 inch plates.
• Strong collaboration with stakeholders.
Corning and HOYA

Improved ULE® Glass Substrates for EUVL Masks Blanks

Carlos Duran, Kenneth Hrdina and Junichi Yokoyama
Corning Incorporated

Tsutomu Shoki, Toshihiko Orihara, Shoji Kaneko and Osamu Maruyama
Hoya Corporation

2013 International Symposium on Extreme Ultraviolet Lithography
Toyama, Japan, Oct. 7–10, 2013
## Technology relationship

<table>
<thead>
<tr>
<th>ArF blank technology</th>
<th>EUV blank technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defect control of quartz</td>
<td>Defect control of LTEM</td>
</tr>
<tr>
<td></td>
<td>Defect control of Mo/Si multilayer</td>
</tr>
<tr>
<td>Defect control of films</td>
<td>Defect control of films</td>
</tr>
<tr>
<td>- Ta binary (ABF)</td>
<td>- Ta alloy absorber and backside film</td>
</tr>
<tr>
<td>- Cr absorber (TFCx, EBTx)</td>
<td>- CrN backside film</td>
</tr>
<tr>
<td>Flatness (~200nm, single side)</td>
<td>Flatness (~30nm, both sides)</td>
</tr>
<tr>
<td>Methodology tools</td>
<td>Methodology tools</td>
</tr>
<tr>
<td></td>
<td>ABI</td>
</tr>
<tr>
<td>DUV control</td>
<td>DUV reflectivity control</td>
</tr>
<tr>
<td></td>
<td>EUV reflectivity control</td>
</tr>
<tr>
<td>Matured production engineering. Commitment</td>
<td>Automated blank manufacturing line.</td>
</tr>
<tr>
<td>to HVM.</td>
<td></td>
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</tbody>
</table>

Methodology tools:
- ABI

DUV control:
- DUV reflectivity control
- EUV reflectivity control

Matured production engineering. Commitment to HVM.
Difficulties of EUV blanks development

- Many of the challenges in EUV mask blanks are in defects.

Defect is **simple**: only three sources
- Defect=Defect from (substrate + deposition + environment)

Defect is **difficult**: only three sources but hundreds of root-causes
- Defect=Defect from (substrate + deposition + environment)
There is no reason that EUV blanks requirement is looser than optical blank.
Entire thickness of EUV blanks is thick: >3times than optical blank. It means that the chance of particles contamination during film deposition is also >3times. IBD (Ion Beam Deposition) is a unique technology for EUV.
And do not forget. We have a backside film.
In total, entire process is long: yield is an issue unless good production engineering & control are maintained.
Difficulties of EUV blanks development

Not only defect..

- ML Defect Quality
- Substrate Defect Quality
- Substrate Flatness BOW
- ULE Substrate CTE: 0+/−5ppb
- Back Side Defect Quality
- ML, Capping-Layer, ABS Requirements (Defect, CW, EUV-R, Durability, etc.)
- FM (Fiducial Mark)
Defect reduction

Defect identification
- Inspection tool
- LT Magics
- Teron
- ABI
- Location

Failure Analysis
- SEM-EDX
- FIB-SEM
- CS-TEM
- AFM
- XPS
- Auger
- ...

Root cause verification
- Substrate
- Deposition
- Environment

Preventive action
- Substrate
- Deposition
- Environment

• Failure Analysis is the key.
• Sematech MBDC (Mask Blank Development Center) associate member (2011-2014)
Ion beam sputter deposition

**Defect source**
- Remained particles in chamber
- Film peeling from chamber
- Particles on beam grid
- Overspray
- Nodules on target surface
- Particles during transferring
- Mechanical motion
- Chucking
...And many others...

[Diagram showing the process of ion beam sputter deposition with labeled parts: Beam source, Ion beam, Sputtered material, Substrate, Target [Mo/Si]]
## Defect database

<table>
<thead>
<tr>
<th>Priority</th>
<th>Composition</th>
<th>Ratio</th>
<th>Shape</th>
<th>Factor</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>14%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>10%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>29%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>D</td>
<td>5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>10%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G</td>
<td>10%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>10%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Schedule

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dec</td>
<td>Jan</td>
</tr>
<tr>
<td>Parts packing</td>
<td>Shield cleaning</td>
<td>Manual handling</td>
</tr>
<tr>
<td>Shield roughness</td>
<td>Shield heat expansion</td>
<td>Plasma chamber</td>
</tr>
<tr>
<td>GV</td>
<td>GV cleanliness</td>
<td>Remained H2O</td>
</tr>
<tr>
<td>Substrate cleanliness</td>
<td>Pre deposition cleaning</td>
<td></td>
</tr>
</tbody>
</table>

### Priority Composition Ratio Shape Factor Improvement

- **A**: 14% (improvement details)
- **B**: 10% (improvement details)
- **C**: 29% (improvement details)
- **D**: 5% (improvement details)
- **E**: 5% (improvement details)
- **F**: 5% (improvement details)
- **F**: 10% (improvement details)
- **G**: 10% (improvement details)
- **A**: 10% (improvement details)
Small size defects

Defect Counts

Residue (Detection Intensity) – Sensitivity

Teron 23nm

Teron 25nm

M1350

EUVL symposium 2016
HOYA EUV Blank Defect Reduction (Champion Grade)

Inspection area: in 100x100mm

- @25nmSEVD
- @20nmSEVD
- @16nmSEVD
- @<16nmSEVD
HOYA EUV Blank Defect Reduction history (Teron, Champion Grade)

10,000 def @23nm SEVD in Q1/CY2012

0 def @23nm SEVD in Q1/CY2016

Area: 132x104mm (max. exposure area)
EUV FM Blank Development

- **Low defects ML blank**
  - Defect inspection
    - Teron Phasur
    - ABI

- **Defect mitigation process**
  - FM process development
    - No particle and Reasonable process
    - Correction process for High position accuracy

- **Defect free mask**
  - Data conversion to the standard grid

- **FM blank process** is under development for defect mitigation process.
HOYA EUV FM Blank

- Fiducial Mark (FM): SEMI-FM
- Defect inspection on Ru-ML
  - Teron (@23nmSEVD) or ABI
- Corrected inspection data on Ru-ML
  - Conversion to the standard grid by original correction
  - Relative defect coordinate to FM (Origin: Blank center)
- All of ML blank defects can be managed to the FM

Defect mitigation test

- HOYA FM blank is workable for defect mitigation process at customers.
- Challenging to further development for achieving higher position accuracy.
Flatness

There are techniques to achieve flatness <10nm, but at a cost of process time and probably defects.

For EUV-HVM application, “viable” solution is needed.
Absorber development

Reflectivity 2% over 30nm Ni thickness.
Minimum reflectivity can be obtained at 39.5nm.

Ref. Development of thin absorber for EUV blanks
Yohei Ikebe, Tsutomu Shoki, Takahiro Onoue
Presented at EUVL symposium 2016 on 24Oct.
Backside Film Development

- **High CoF (Coefficient of Friction)**
- **CrN Back side film (Standard)**
- **Small Bow (Blank flatness)**

- Higher CoF is needed to more firmly hold the reticle at high accelerations.
- Higher CoF is needed to more firmly hold the reticle at high accelerations.
- High adhesion and high wear durability are useful for stable and damageless e-chucking.

- Smaller bow of <300nm is required for meeting the NXE overlay requirement for 16nmhp.
- Good cleaning durability
- Good stress controllability

- **Ta based films**

- **Graph**
  - Bow (nm)
  - CoF (A.U)
  - CrN-1
  - CrN-2
  - TaX-1
  - TaX-2
  - TaX-3

- HOYA developed TaX-3 (TaB) backside film for higher CoF and smaller bow.
- Very small bow can be produced by application of Ta based back side film.
### HOYA TaB Backside Film

<table>
<thead>
<tr>
<th>Requirement</th>
<th>CrN (Standard)</th>
<th>TaB (New)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sheet Resistance</strong></td>
<td>&lt;100 Ohm/sq.</td>
<td>Pass</td>
</tr>
<tr>
<td><strong>Surface roughness</strong></td>
<td>≤0.6nm Rms</td>
<td>Pass</td>
</tr>
<tr>
<td><strong>Scratch test</strong> [Critical load mN]</td>
<td>Better than CrN</td>
<td>Pass (2x better)</td>
</tr>
<tr>
<td><strong>Wear rate</strong> [X10⁻⁷ mm³/Nmm]</td>
<td>Better than CrN</td>
<td>Pass (5x better)</td>
</tr>
<tr>
<td><strong>CoF</strong></td>
<td>&gt;0.3</td>
<td>Pass &gt;0.3</td>
</tr>
<tr>
<td><strong>Bow</strong></td>
<td>300nm</td>
<td>Pass (3x better)</td>
</tr>
</tbody>
</table>

*Measured by ASML under their definition

- TaB film passed all of the requirement for e-chucking process.
- TaB showed better performance in scratch and wear test than CrN.
Summary

Defect performance:
• Defect performance has significantly improved over the past 6 years.
  • Steady defect analysis work and aggressive trials for defect improvement
  • Integration with HOYA production technologies
  • Collaboration with key stakeholders
• Correlation with defect printability.

EUV blanks for HVM:
• Aggressive proposals such as TaB backside film
• Total performance including factors other than defects
• Maturity is required. It will be brushed up through actual exposure.

EUV blanks for the next:
• Beside defects. Acceleration of development, for example absorbers.
• Support from stakeholders for investment toward HVM.
Mask Blank is considered as a high risk key item for EUV Lithography.

A first step toward maturity.
Acknowledgement

- Hoya team
- Great appreciation to ASML team for evaluation of TaB backside film.