Defect inspection and characterization on actinic blank inspection tool

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2. Defect printability
3. Defect characterization
4. Summary
ABI tool development status

Dark field inspection

Back Illuminated CCD camera
Schwarzschild optics
EUV light for illumination
Mask blank

Inspection signal
Defect

Phase defect
Bump defect
Pit defect
Multilayers
substrate
substrate

Capture Rate, Programmed defects

Height Width 0.8 1 1 1 0.95 1.2 nm
32 36 41 43 55 56 nm

Actinic inspection

K. Goldberg et al., “Defect detection and inspection unmasked”, IWEUVL, 2010

Tsuneo Terasawa et al., Development of actinic full-field EUV mask blank inspection tool at MIRAI-Selete, Proc. of SPIE vol. 7271 (2009)

ABI HVM Tool is ready to play an important role in phase defect control
EIDEC/Lasertec BI Program Schedule

- **Tool Design**
  - Parts Fabrication
  - Development
  - Improvement

- **Prototype tool for HVM 16nm hp**
  - Inspection started
  - Additional 1200x Review function fabrication evaluation

- **Prototype tool upgrade**
  - Printability study
  - Inspection capability evaluation
  - Location accuracy evaluation

- Defect classification

Achieved Basic performance

1) BI Program: Blank Inspection program
ABI tool – inspection performance

- The ABI tool inspected more than 200 $\times 10^4$ mm$^2$ in one year.
- Signal intensity has been stable during this period.
- The ABI tool meets the 16nm-sensitivity requirement and is currently being used for actual EUV mask blanks inspection.

The ABI tool has demonstrated its actinic inspection performance through a year of operation.
ABI tool - review function

- Actinic review is available for all defects detected by the ABI tool.
- The ABI tool performed more than 80,000 reviews in one year.

Actinic review function is crucial for understanding defect characteristics
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Previous studies on printability of phase defect

Relation between Printability simulation and experiment

<table>
<thead>
<tr>
<th>Defocus [nm]</th>
<th>-30</th>
<th>0</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Printed 24 nm L&amp;S, Pit phase defect @mask (W=80 nm, D=1.9 nm) NA=0.25, Dipole</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Simulation study for Wafer impact as a function of ABI intensity

Simulation shows ABI signal intensity proportionally correlated to defect intensity on wafer.
Printing impact from ABI signal intensity

Experimental ABI signal intensity as a function of phase defect size

- 10% CD error for 16nm hp
- ABI detection threshold

 ABI signal intensity represents wafer printing impact
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Defect characterization – ABI flow

Defect Inspection

Low Magnification Review

High Magnification Review

- Defect map with DSI (defect signal intensity)
- False elimination
- Phase / Amplitude defect classification
- Measurement of defect location and size
- Pit/Bump classification

Review of each defect

high resolution

1μm
# Phase / Amplitude defect classification

<table>
<thead>
<tr>
<th>Defect type</th>
<th>EUV review</th>
<th>DUV review</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase Defect (H2.4nm, W200nm)</td>
<td><img src="image1.png" alt="EUV image" /></td>
<td><img src="image2.png" alt="DUV image" /></td>
</tr>
<tr>
<td>Amplitude Defect (H50nm, W76nm)</td>
<td><img src="image3.png" alt="EUV image" /></td>
<td><img src="image4.png" alt="DUV image" /></td>
</tr>
</tbody>
</table>

With EUV and DUV reviews, Phase/Amplitude can be distinguished.

**DUV review function**
- **DUV**
  - $\lambda=193\text{nm}$
  - Schwarzschild optics

- H22nm x W50nm carbon deposits observable in DUV review
Pit and Bump - Through focus images

Low magnification images

<table>
<thead>
<tr>
<th></th>
<th>-2.0um</th>
<th>-1.0um</th>
<th>0.0um</th>
<th>1.0um</th>
<th>2.0um</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIT ((-1.7\times63\text{nm}))</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
</tr>
<tr>
<td>BUMP ((0.9\times72\text{nm}))</td>
<td><img src="image6.png" alt="Image" /></td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
</tr>
</tbody>
</table>

High magnification images

<table>
<thead>
<tr>
<th></th>
<th>-2.0um</th>
<th>-1.0um</th>
<th>0.0um</th>
<th>1.0um</th>
<th>2.0um</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIT ((-2.4\times204\text{nm}))</td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
<td><img src="image13.png" alt="Image" /></td>
<td><img src="image14.png" alt="Image" /></td>
<td><img src="image15.png" alt="Image" /></td>
</tr>
<tr>
<td>BUMP ((0.9\times232\text{nm}))</td>
<td><img src="image16.png" alt="Image" /></td>
<td><img src="image17.png" alt="Image" /></td>
<td><img src="image18.png" alt="Image" /></td>
<td><img src="image19.png" alt="Image" /></td>
<td><img src="image20.png" alt="Image" /></td>
</tr>
</tbody>
</table>

The position where the image focuses differs, depending on whether the defect is pit or bump.
Pit / Bump classification function

Through focus image analysis for pit/bump classification

Focus dependent intensity profiles for programmed phase defects

Details of focus dependency, see reference poster session “The influence of phase defect characteristics on scattered light images in actinic dark field inspection” Noriaki Takagi, EIDEC

With through focus image analysis, Pit/Bump classification is possible.
## Defect size measurement

### Programmed phase defect images from high magnification optics

<table>
<thead>
<tr>
<th>Defect width by AFM</th>
<th>72nm</th>
<th>101nm</th>
<th>108nm</th>
<th>120nm</th>
<th>154nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defect images by high Mag. review</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
</tr>
<tr>
<td>Defect Diameter from ABI images</td>
<td>55nm</td>
<td>76nm</td>
<td>95nm</td>
<td>112nm</td>
<td>120nm</td>
</tr>
</tbody>
</table>

With ABI high magnification review images, defect size measurement is possible.

Comparison of measurement results from ABI review and AFM

![Graph](image6.png)
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Summary

1. The ABI HVM prototype performs EUV blank inspection and review to assist the efforts to develop better EUV blanks.

2. ABI review images facilitate the following defect characterization, which contributes to EUV blank defect management.
   - Phase/Amplitude classification
   - Pit/Bump classification
   - Defect size measurement
Acknowledgements

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Thank you very much for your attention.

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