Flatness Compensation
Updates/Challenges

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Outline

• Results
  – Overlay Results from Wafer Exposures on Alpha-Demo-Tool (ADT)
  – Analysis on Residual Field Signature
  – Summary

• Issues on Mask Flatness Compensation
  – Methodology General
  – Issues
    o Polynomial Fits for Flatness Raw Data
    o Flatness Metrology

• Future Plan

• SEMI Standard Flatness Specification

• Open Discussion
# Overlay Data from Exposed Wafers on ADT

: Single Machine Overlay with Multiple Masks

<table>
<thead>
<tr>
<th>Layout</th>
<th>$X_{\text{max}}$</th>
<th>$\sigma_x$</th>
<th>$Y_{\text{max}}$</th>
<th>$\sigma_y$</th>
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</thead>
<tbody>
<tr>
<td>Uncomp</td>
<td>3.5</td>
<td>3.4</td>
<td>6.8</td>
<td>8.9</td>
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<td>UW FEM</td>
<td>3.2</td>
<td>3.3</td>
<td>4.3</td>
<td>5.6</td>
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<tr>
<td>UW AM</td>
<td>3.1</td>
<td>3.1</td>
<td>4.9</td>
<td>5.4</td>
</tr>
<tr>
<td>NuFlare AM</td>
<td>3.2</td>
<td>3.7</td>
<td>5.0</td>
<td>6.3</td>
</tr>
</tbody>
</table>

- **Compensation IMPROVES overlay**
  - All models improved overlay by 29% to 39%.
- Data suggest that the analytical method is sufficient for pilot-line production.

- ADT machine overlay with single mask (zero nm mask non-flatness error) is ~3 nm.
Overlay Analysis

• The compensation did not do as well as predicted.
  – ~30% improvement vs. over 50% expected

• Possible Reasons
  – The ADT’s best SMO data are approximately ~3 nm max error
  – Non-flatness of ‘Flat’ mask
  – Flatness metrology errors including gravity by holder
  – E-beam writer tool error during mask building
  – Reproducibility error during mask chucking in scanner

• These errors could create a residual field signature, which could be removed by subtracting the signature from the uncompensated data.
Summary

- First commercial EUV masks were built with non-flatness compensation schemes.
- ‘Flat’ and ‘Non-flat’ masks used for overlay test on ADT.
- Overlay Result

The overlay results showed that the flatness compensation methodology works to reduce overlay errors with > 300 nm ‘Non-flat’ substrate.
- Data suggest that analytical method is sufficient for flatness compensation.
Summary (continued)

• Non-flatness compensation is a key enabler for EUV lithography.

• SEMATECH and partners demonstrated for the first time that non-flatness correction work.

• Flatness compensation should have a major impact on mask cost
  – enables relaxed flatness standards
  – easier to meet defect requirements (flatness/defectivity trade-off).
Future Plan

• SEMATECH is planning to build another set of ‘Flat’ and ‘Non-flat’ commercial masks.
  – Overlay study on ADT will be done using ‘Flat-A’ / ‘Flat-B’ masks
    o Identify the best possible overlay without compensation
  – Comparison with ‘Non-flat’ to ‘Flat’ will verify if we can achieve equivalent results using non-flat masks with compensation

• Compensation methodology needs to be further refined with testing on PPT tools with tighter overlay budget.
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  – Summary

• Issues on Mask Flatness Compensation
  – Methodology General
  – Issues
    o Polynomial Fits for Flatness Raw Data
    o Flatness Metrology
    o Modeling Mis-connects

• Recommended Flatness Specification

• Open Discussion
Flatness Compensation Methodology

1. Measure Blank flatness on both sides
2. Model effect of chucking the bowed mask flat in scanner
3. Calculate image placement errors due to residual z-height after chucking
4. Generate a table of combined errors
5. Reverse the sign of the errors → compensation table
6. Compensation table is added into the e-beam job deck
7. Expose wafers in ADT using both ‘Flat’ and ‘Non-flat’ masks
8. Measure the overlay of ‘Non-flat’ mask to ‘Flat’ mask
Substrate Flatness Data
Quality Area 142 × 142 cm²

‘Flat’ Substrate
(State-of-the-art flatness)

Front
66 nm

Back
62 nm

‘Non-flat’ Substrate
(Typical optical flatness)

576 nm
429 nm
Introduction – residual z-height targets

ITRS Roadmap (2007): Requirements for Masks

<table>
<thead>
<tr>
<th>All values are on the mask</th>
<th>2009</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required Mask Image Placement (IP)</td>
<td>6.4nm</td>
<td>3.8nm</td>
</tr>
<tr>
<td>EUV Substrate Flatness</td>
<td>57nm</td>
<td>36nm</td>
</tr>
<tr>
<td>» IP contribution from Z height</td>
<td>5.7nm</td>
<td>3.6nm</td>
</tr>
</tbody>
</table>

Almost the whole budget!

- Aggressive polish is required to achieve EUV flatness values
  - aggressive polish adds time and cost, and can add defects
  - could result in too high a Cost-of-ownership for EUVL.
- The industry desires a method to predict and compensate for non-flatness effects
  - Thus use same flatness requirement for EUV and Optical substrates

Even tighter flatness will be required!

Comparison of LTEM substrates ordered at 100nm versus ~250nm flatness.
Includes adders from shipping and metrology.
FEM Modeling Results
- Chucked reticle OPD of ‘Non-flat’ blank
- Plots cover an area of $132 \times 132 \text{ mm}^2$

- **Reticle OPD (FE Simulation)**
  - 8x8 Polynomial Fit
  - P-V = 516 nm

- **Thickness Variation Fitted Data**
  - 8x8 Polynomial Fit
  - P-V = 517 nm

- **Thickness Variation Raw Data**
  - P-V = 537 nm

- **TV delta Raw Data – Fitted Data**

- Max. Difference = 40 nm

- Raw thickness variation (frontside – backside) is a good approximation of final chucked front-surface

- **Polynomial fitting misses high frequency data**
  - It could be real flatness variation and/or from metrology errors
  - Could create limit to how far compensation can be extended
SEMATECH Experimental Set-up

12 inch Diameter Beam Expander

Vertical Holder for Substrate/Blank Flatness Measurements
Measurement Reproducibility

Set 1

PV = 103 nm

Set 2

PV = 111 nm

Set 3

PV = 105 nm

Set 1 – Set 2

PV = 27 nm

Set 1 – Set 3

PV = 21 nm

Note: Loading / Unloading steps were in between each Set.
Flatness Metrology Improvement

- Need to improve flatness metrology accuracy for pilot-line and HVM.
- SEMATECH initiated a program with NIST proposed metrology setup to generate ‘Reference Standard’ substrates and blanks.
  - Blank suppliers will use ‘Reference Standards’ to characterize and improve their metrology capability.

![Diagram of metrology setup with labeled components: collimator, 45° folding mirror, substrate & tray (hidden), Reference flat, Liquid Tray]
SEMI P37 Flatness Specification

- There are two possible strategies that could be used when specifying flatness requirements for mask substrates and the final bow requirement on the blanks; *one using relaxed requirements if the Mask Pattern Generator shall make use of a flatness compensation scheme to adjust image placement due to substrate non-flatness and blank bow, and the other with tight specifications on substrate flatness and blank bow if no correction of image placement (for non-flatness) is possible at the Mask Pattern Generation step.*

**Table 5 Suggested Substrate Flatness and Blank Bow Specifications for 2010 – 2012 time frame**

<table>
<thead>
<tr>
<th>Item</th>
<th>No Mask Pattern Compensation for non-flatness</th>
<th>With use of Mask Pattern Compensation for non-flatness</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frontside Flatness and Backside Flatness with wedge and bow removed Within Flatness Quality Area</td>
<td>30 peak-to-valley</td>
<td>300 peak-to-valley</td>
<td>nm</td>
</tr>
<tr>
<td>Total Blank Bow Over Flatness Quality Area</td>
<td>≤ 600 peak-to-valley</td>
<td>≤ 2000 peak-to-valley</td>
<td>nm</td>
</tr>
</tbody>
</table>
Open Discussion