High accuracy photomask flatness data for write compensation and process development for EUV image placement error relief

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EUVL 2016
Outline

• Topographic Error Contributions
  – Meeting the error budget

• Flatness measurement methodology
  – Optical vs. functional tolerances

• Flatness Compensation File
  – The importance of orientation
  – Illumination error contribution

• Demonstrated results

• Conclusion/Future work
**How Flatness Translated to Image Distortions**

Out of Plane Distortion

\[ \Delta x = \Delta z \times \tan \phi \times M \]

In Plane Distortion

\[ \Delta x = k \times T \times \frac{\delta z}{\delta x} \times M \]

*NS of patterned mask is typically located between 1/2T and 1/3T

Neutral Surface Location

Photomask Thickness

Local Slope

Magnification

CORNING | Tropel Metrology Instruments
## Flatness Specifications (1)

<table>
<thead>
<tr>
<th>Node</th>
<th>Resolution</th>
<th>2013 ITRS</th>
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8X magnification starts being used for distortion calculations

Last published specs from ITRS

### NXE technology roadmap - Extendibility

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*Budgeted overlay is wafer scale, all other values are reticle scale*
## Flatness Specifications (3)

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all other values are reticle scale

Sometimes Our World Is NOT Flat

Flatness must be < 8.5 nm

Scale to the size of a baseball stadium

Flatness must be < 5.6 μm

Curvature from the earth results in….

196 μm of shape!

35X out of spec
Previous Method

EUV flatness as defined by ITRS 2013

We want the flatness data to emulate the state of the photomask at the chuck

Maximum deviation from center to edge

Flatness Measurement Taken
- Vertical “Free Standing Position”
- 4 rotations for averaging

2nd Order Removed from Results
- 2nd order removed at scanner
- 2nd order from thickness variation is not corrected by scanner

Thickness Variation
- Was not included in ITRS

*Analysis conducted with uncoated blank from 2014

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Backside Print

Analysis of a relation between the spatial frequency of electrostatic chuck and induced mask inplane distortion (IPD)

Takeshi Yamamoto\textsuperscript{a}, Kazuya Ota\textsuperscript{b}, Naosuke Nishimura\textsuperscript{b}, Shin’ichi Warisawa\textsuperscript{a}, Sunao Ishihara\textsuperscript{a}

- FEA and Analytical methods are used to determine spatial frequency print through factor
- Low spatial frequencies transfer 100%
- High spatial frequencies not likely to transfer
- Discrepancies exist between the two above methodologies for mid-spatial frequencies (4\textsuperscript{th} - 10\textsuperscript{th} order)

![Chart showing transmission percentage vs. polynomial order](chart.png)

Mid spatial frequency uncertainty

*Chart is for visualization purposes only*
Band Pass Backside Measurement

Everything up to 10\textsuperscript{th} order will transfer during chucking

Need to eliminate components that transfer non-uniformly

Component of backside flatness that non-uniformly transfers during chucking
Proposed FrontSide Flatness Methodology

12th Order - Correctable Flatness

Spatial Frequencies which have the potential to transfer during chucking

Non-Correctable Flatness

Clamped Front Flatness

10th Order Backside

Residual which can be improved through blank manufacturing and improved metrology

Averaging of 4 orientations

Front Flatness_Raw

65.3nm

Clamped Front Flatness

51.2nm

Back Flatness_Raw

76.5nm

10th Order Backside

44.5nm

Bokeh analysis of 2nd order removed

12th Order Backside

44.5nm

Spatial Frequencies which have the potential to transfer during chucking

Averaging of 4 orientations

Used for compensation file creation

12th Order Backside

44.5nm

10th Order Backside

44.5nm

Non-Correctable Flatness

12.3nm

Clamped Front Flatness

51.2nm

Spatial Frequencies which have the potential to transfer during chucking

Used for compensation file creation

12th Order Backside

44.5nm

Spatial Frequencies which have the potential to transfer during chucking

10th Order Backside

44.5nm

Residual which can be improved through blank manufacturing and improved metrology

Analysis conducted with uncoated blank from 2014
Outline

• Topographic Error Contributions
  – Meeting the error budget

• Flatness measurement methodology
  – Optical vs. functional tolerances

• Flatness Compensation File
  – The importance of orientation
  – Illumination error contribution

• Demonstrated results

• Conclusion/Future work
IPD Calculations

- For our evaluation the neutral surface (NS) was positioned at the midway point between 1/2T and 1/3T
  - NS will vary depending on pattern density, and fill stack variables
  - This position minimizes the potential error from the misplacement of the NS
- The slope was calculated using a 15x15 mm kernel
- Values shown are at reticle scale

Extremes of NS position can shift the magnitude of IPD values 20%
OPD error contribution from illumination

- NXE illumination is non-telecentric
- Illumination profile must be split into X and Y components, and applied to the OPD to find the corresponding IPE_{OPD}

\[ IPE_{OPD_X} = \frac{z \cdot x}{\tan \theta \cdot R} \]
\[ IPE_{OPD_Y} = \frac{z \cdot (R^2 - x^2)^{\frac{1}{2}}}{\tan \theta \cdot R} \]

PV: 41.8 nm
PV: 51.7 nm
SEMATECH Photomask Measurement

- 2 very non-flat masks with 4 interleaved flatness compensation overlay targets were exposed in order to demonstrate flatness compensation capabilities
  - Large non-flatness aids in tracking in sign and orientation
- Overlay data obtained from exposures on ASML ADT system
- Flatness calculation from previous slide used for this analysis

Corning calculated OPD errors for both masks from reticle thickness

**PV:** 224.2 nm

**PV:** 556.6 nm
Determine overlay without built in flatness compensation

- Flatness compensation in the overlay data was removed by subtracting the measured registration data from the overlay measurement targets for each reticle
  - Result is same as if flatness compensation is not used with each reticle
  - Note: there are 336 total overlay sites on each reticle

Metrology Layout:

- Metrology layout- Each box represents a different compensation scheme
- All flatness compensation schemes are removed (Raw Data)
Data Verification

- Final results show significant improvement to overlay
- Some systematic errors appear near the top and bottom rows
  - Could be contributed from ADT clamp, metrology or analysis method due to extreme non-flat reticles

\[ X_{error} \rightarrow \text{Decreased by 38%} \quad Y_{error} \rightarrow \text{Decreased by 85%} \]
Compensation File Creation

- Numerous factors during the processing of the correction file impact final results

- This study worked to establish sign and orientation conventions for flatness data collection and compensation file generation
Fishbone Diagram of Overlay Error Contributors

Follow on paper planned to repeat this study with current state of the art metrology and exposure systems, as well as investigate other overlay error contributors.

Write compensation can decrease the error contributions from the reticle fabrication process.
Conclusion

• Physical EUV mask flatness requirements can be relaxed with application of adequate flatness metrology and compensation algorithms
• Adjusting the mask blank flatness requirements to reflect compensation makes the specifications much more achievable, and in a much shorter timescale
• Demonstrated that write compensation provides a strong path to reaching the mask related wafer overlay requirements
  – Sign conventions and orientation for write compensation were established