Flatness Compensation Updates/Challenges

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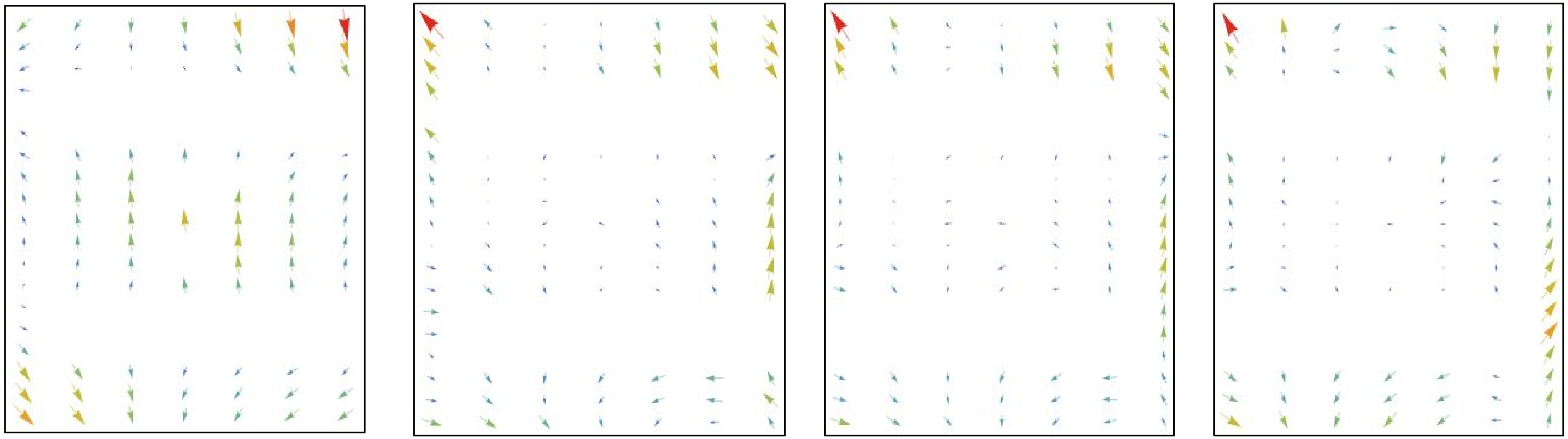
Outline

- 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
    - Polynomial Fits for Flatness Raw Data
    - Flatness Metrology
- Future Plan
- SEMI Standard Flatness Specification
- Open Discussion

Overlay Data from Exposed Wafers on ADT

: Single Machine Overlay with Multiple Masks

Uncompensated | UW FEM | UW AM | NuFlare AM



Layout	X_{max}	$3\sigma x$	Y_{max}	$3\sigma y$
Uncomp	3.5	3.4	6.8	8.9
UW FEM	3.2	3.3	4.3	5.6
UW AM	3.1	3.1	4.9	5.4
NuFlare AM	3.2	3.7	5.0	6.3

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

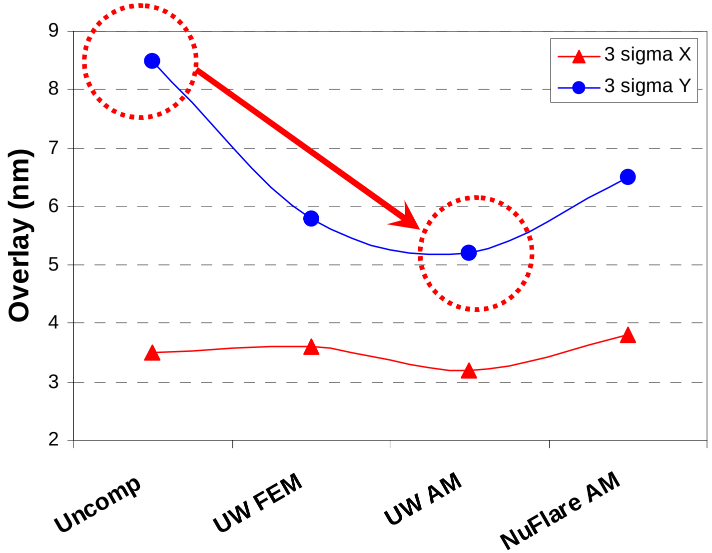
- **Compensation IMPROVES overlay**
  - All models improved overlay by 29% to 39%.
- Data suggest that the analytical method is sufficient for pilot-line production.

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



8.5 nm → 5.2 nm

39% improved

- 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
    - 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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- Issues on Mask Flatness Compensation
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    - Polynomial Fits for Flatness Raw Data
    - Flatness Metrology
    - Modeling Mis-connects
- Recommended Flatness Specification
- Open Discussion

Flatness Compensation Methodology

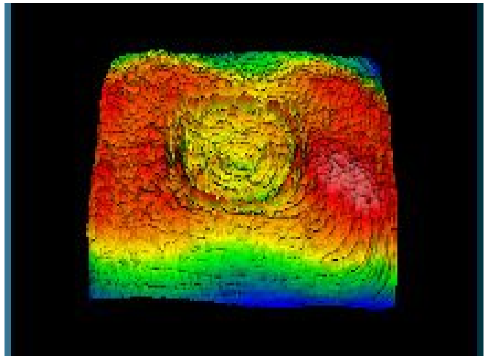
1. Measure Blank flatness on both sides
2. Model effect of chucking the bowed mask flat in scanner
3. Calculate image placement errors due to residual z-height after chucking
4. Generate a table of combined errors
5. Reverse the sign of the errors $\rightarrow$ compensation table
6. Compensation table 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

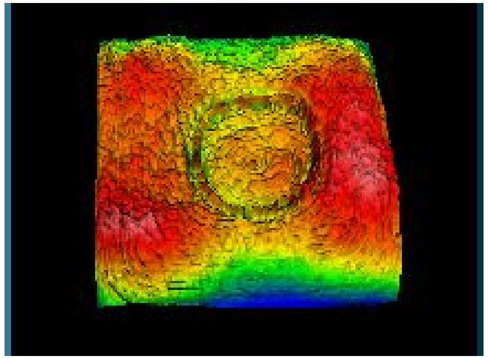
: Quality Area 142 × 142 cm^2

Front | Back

'Flat' Substrate
(State-of-the-art flatness)

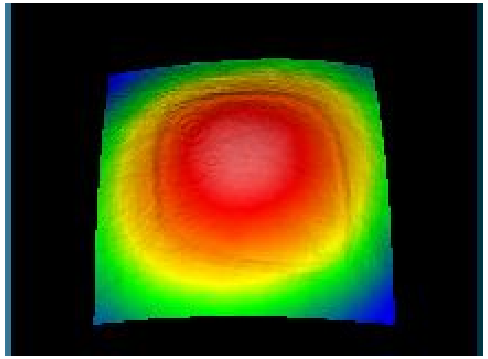


66 nm

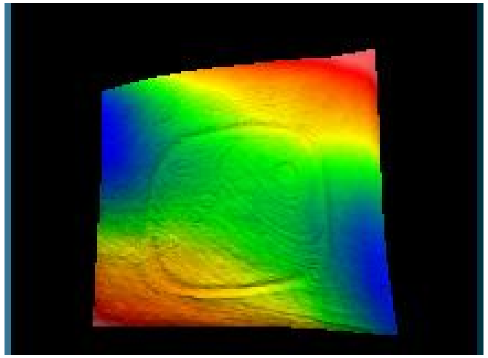


62 nm

'Non-flat' Substrate
(Typical optical flatness)



576 nm



429 nm

Introduction – residual z-height targets

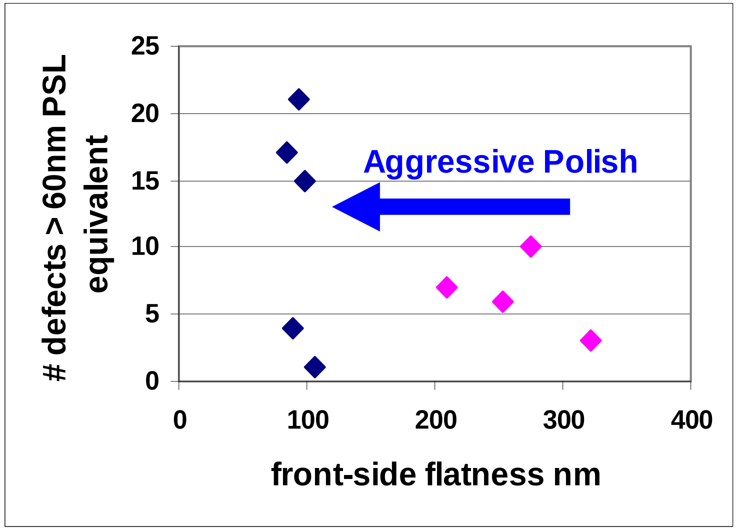
ITRS Roadmap (2007): Requirements for Masks

All values are on the mask	2009	2013
Required Mask Image Placement (IP)	6.4nm	3.8nm
EUV Substrate Flatness	57nm	36nm
» IP contribution from Z height	5.7nm	3.6nm

Almost the whole budget !

Even tighter flatness will be required !

- **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



Comparison of LTEM substrates ordered at 100nm versus ~250nm flatness.

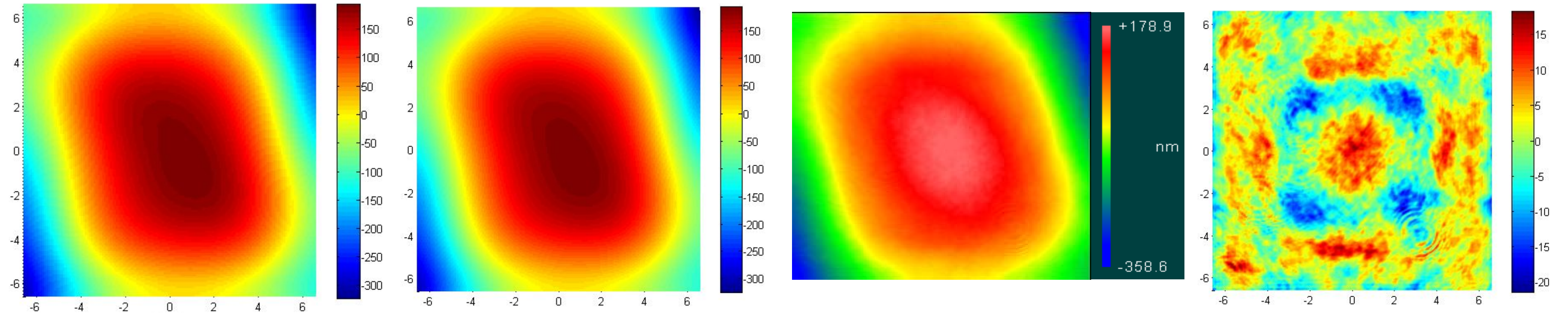
Includes adders from shipping and metrology.

FEM Modeling Results

- Chucked reticle OPD of 'Non-flat' blank

- Plots cover an area of 132 × 132 mm²

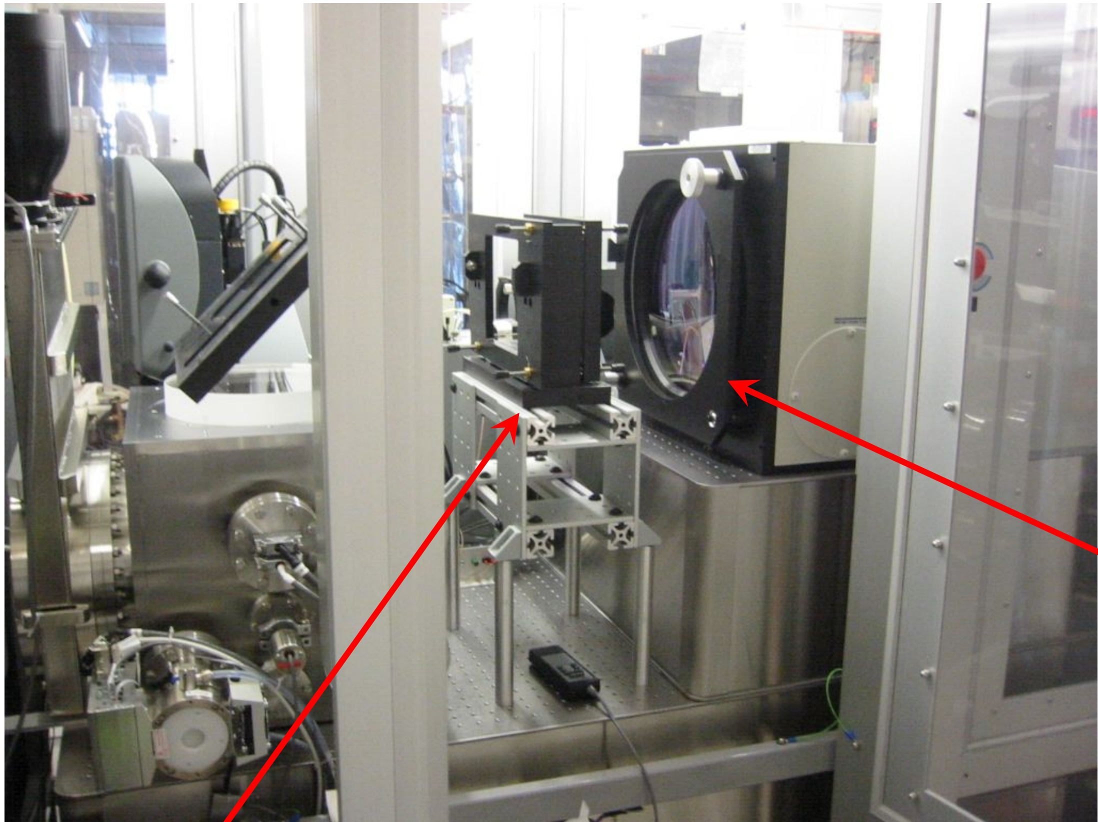
Reticle OPD (FE Simulation) 8x8 Polynomial Fit	Thickness Variation Fitted Data 8x8 Polynomial Fit	Thickness Variation Raw Data	TV delta Raw Data – Fitted Data



P-V = 516 nm	P-V = 517 nm	P-V = 537 nm	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

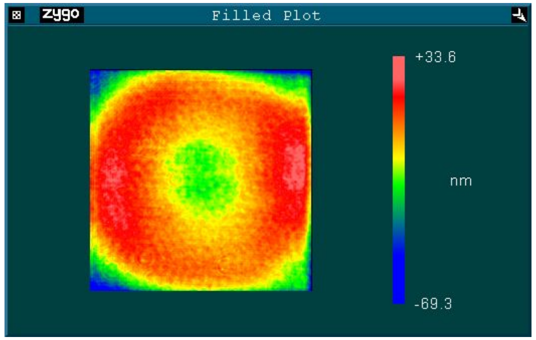


12 inch Diameter
Beam Expander

Vertical Holder for Substrate/Blank Flatness Measurements

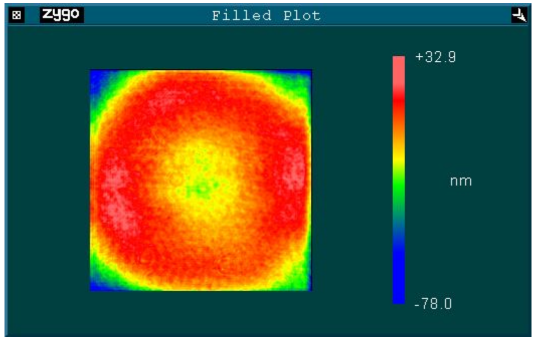
Measurement Reproducibility

Set 1



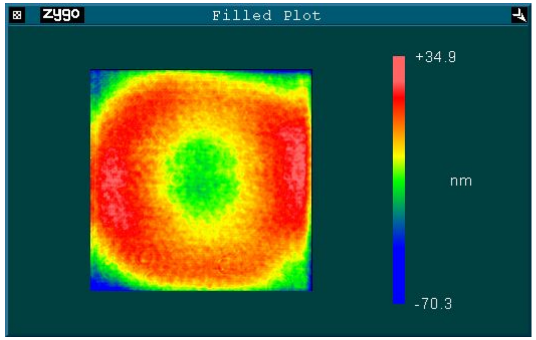
PV = 103 nm

Set 2



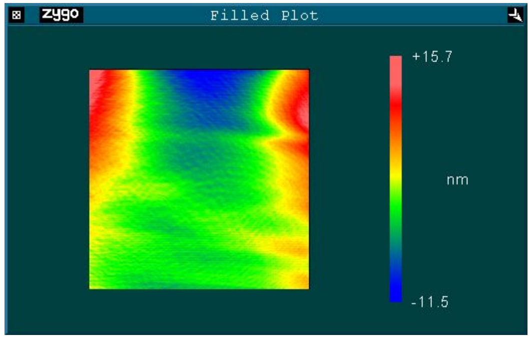
PV = 111 nm

Set 3



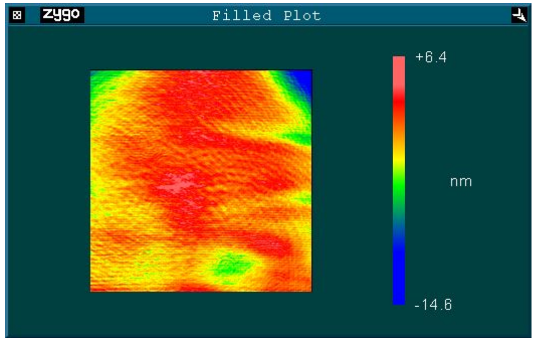
PV = 105 nm

Set 1 – Set 2



PV = 27 nm

Set 1 – Set 3



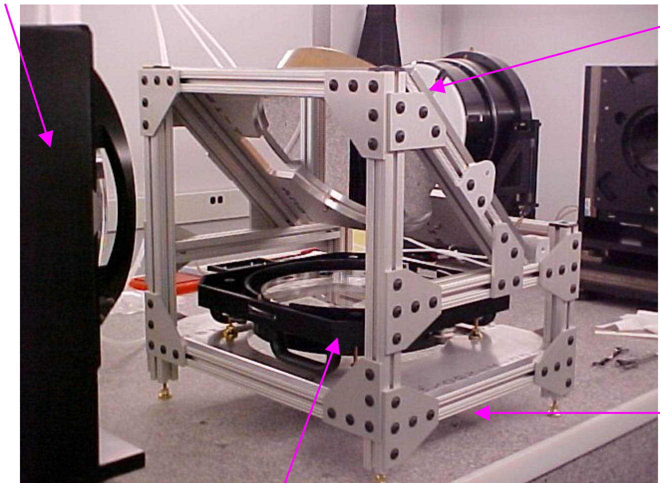
PV = 21 nm

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.

collimator

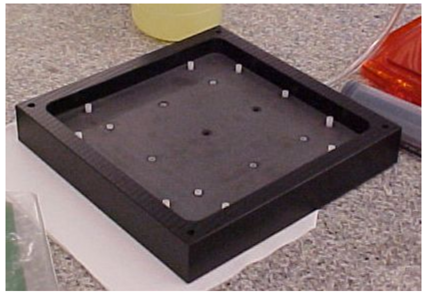


45° folding mirror

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

Item	***No Mask Pattern Compensation for non-flatness***	***With use of Mask Pattern Compensation for non-flatness***	**Units**
Frontside Flatness and Backside Flatness with wedge and bow removed *Within Flatness Quality Area*	30 peak-to-valley	300 peak-to-valley	nm
Total Blank Bow *Over Flatness Quality Area*	≤ 600 peak-to-valley	≤ 2000 peak-to-valley	nm

Open Discussion