Impact of frequent particle removal on EUV mask lifetime

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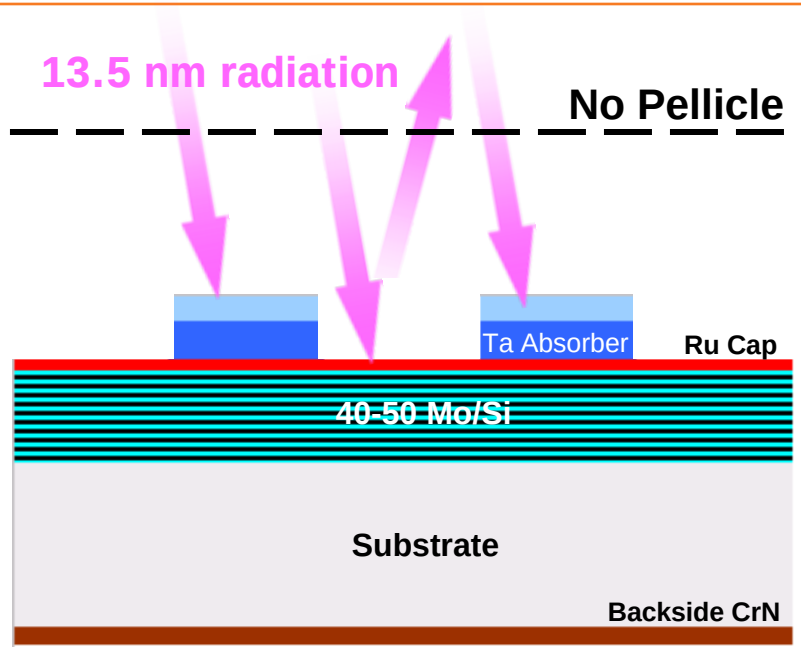
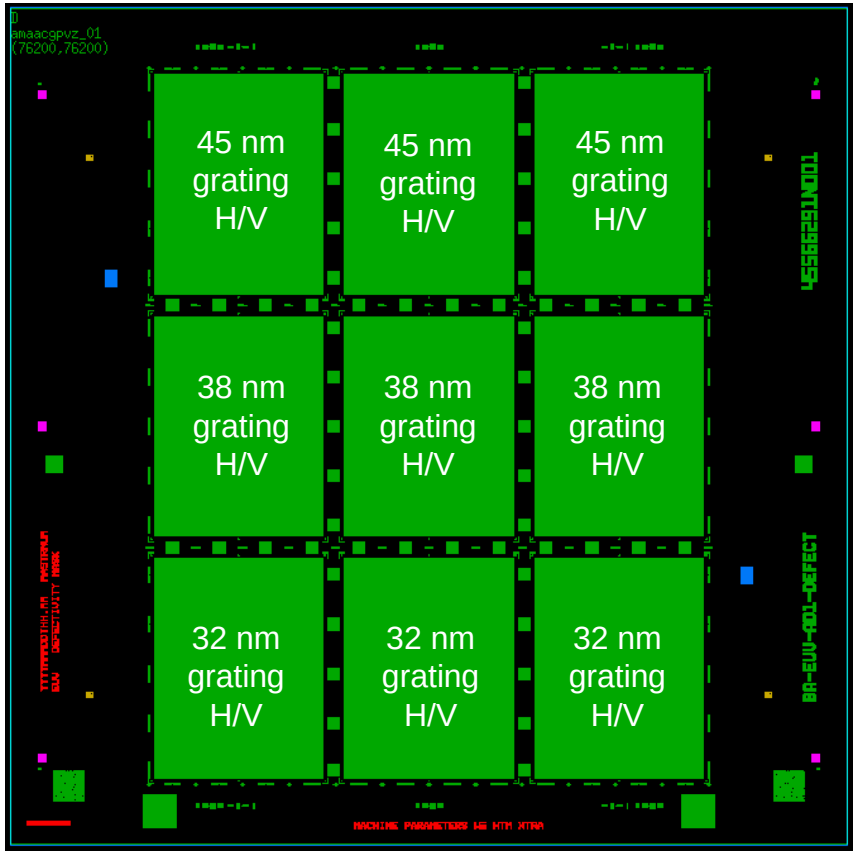
Outline of Presentation

- Introduction
- EUV mask defectivity
  - Shipping, handling & ADT exposure
  - Backside contamination
  - Front side added defects
- EUV mask cleans & characterization
- Conclusions

EUV Mask Architecture

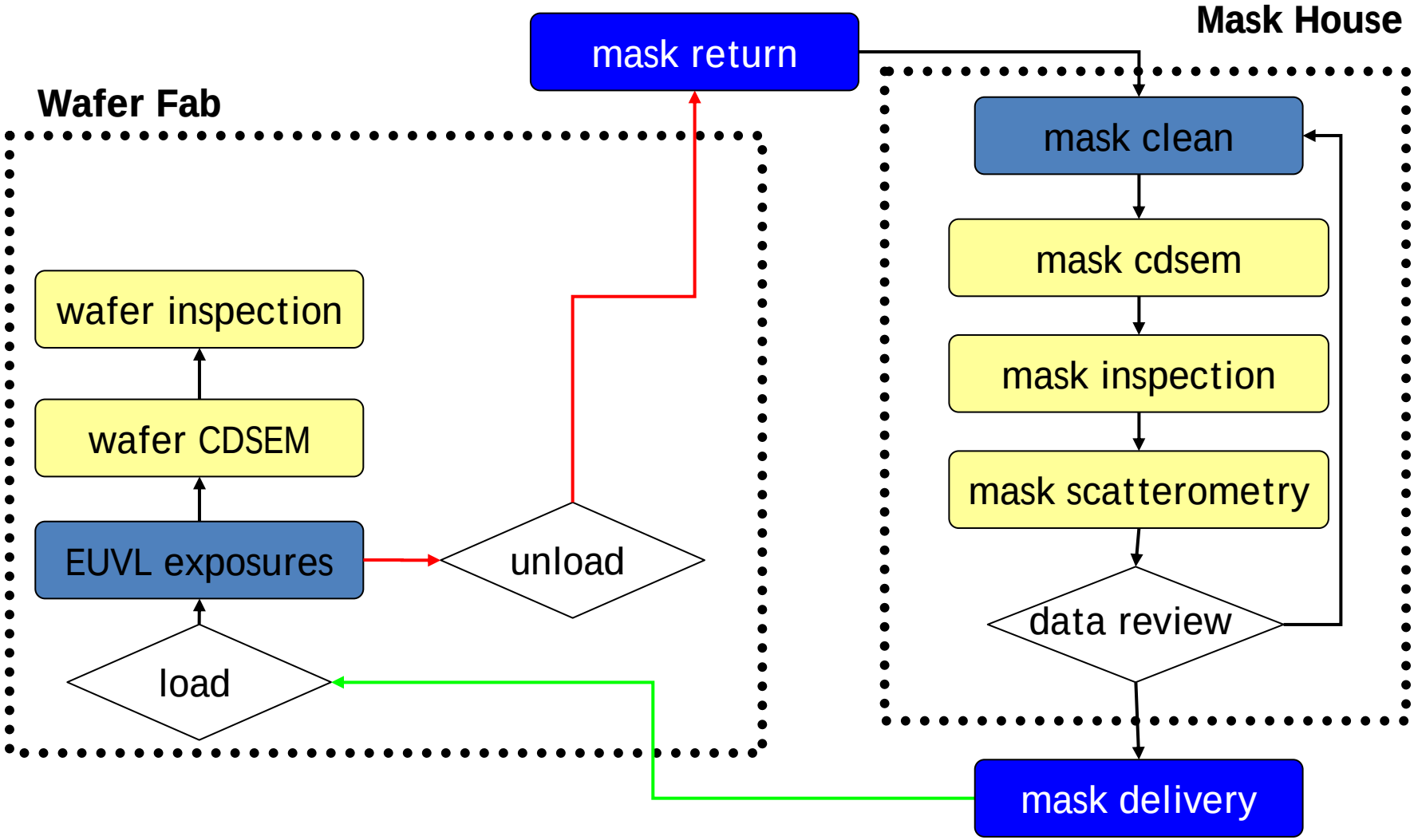


EUV Lifetime Mask Layout



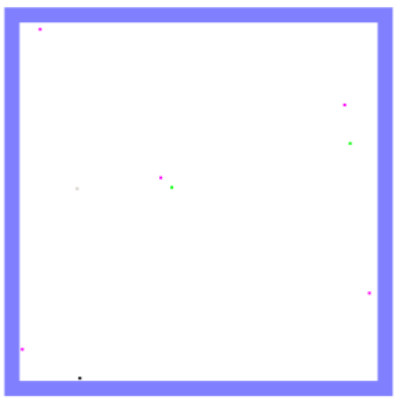
- Mask defectivity specs
  - Substrate: 0 < 35nm
  - Blank: 0 < 29nm
  - Mask: 0 < 29nm
- Mask reflective spec
  - Reflectivity >65% @13.5nm

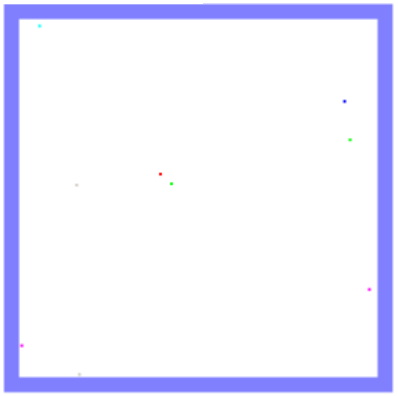
Experimental Flow

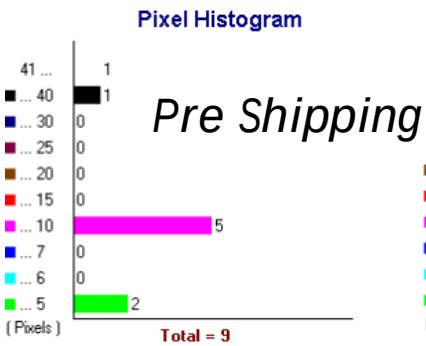


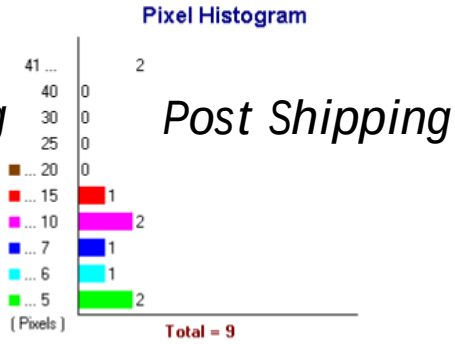
Shipping Defects

- Goal: Determine adders contributed by shipping
- Method:
  - Pre-measure defects
  - Load in dual pod
  - Ship to Albany and back to Burlington
  - Unload from dual pod
  - Measure defects
- Result: Zero adders
  - 9 particles pre and post at same locations
  - Bin-hopping of defect sizes because of tool fluctuations







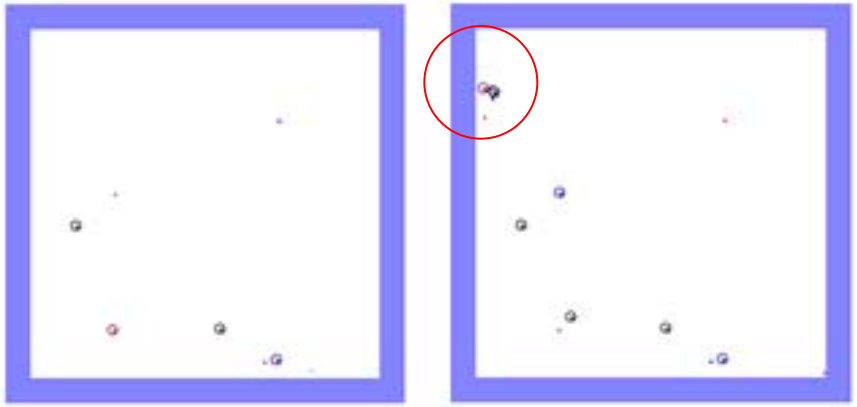


Shipping + ADT Load/Unload Defects

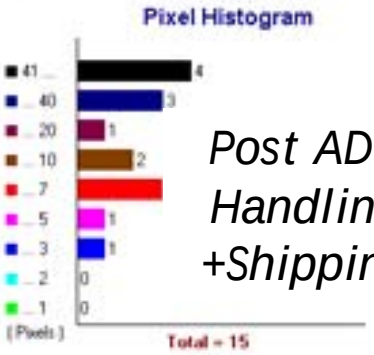
- Goal: Quantify anticipated defects added by exposure tool handling
- Method:
  - Pre-measure defects
  - Load in dual pod
  - Ship to Albany
  - Load/chuck/unload in ADT1
  - Ship to Burlington*
  - Post-measure defects
- Result:
  - New cluster of defects
  - Source could be handling

*External damage to shipping box

+ AD1



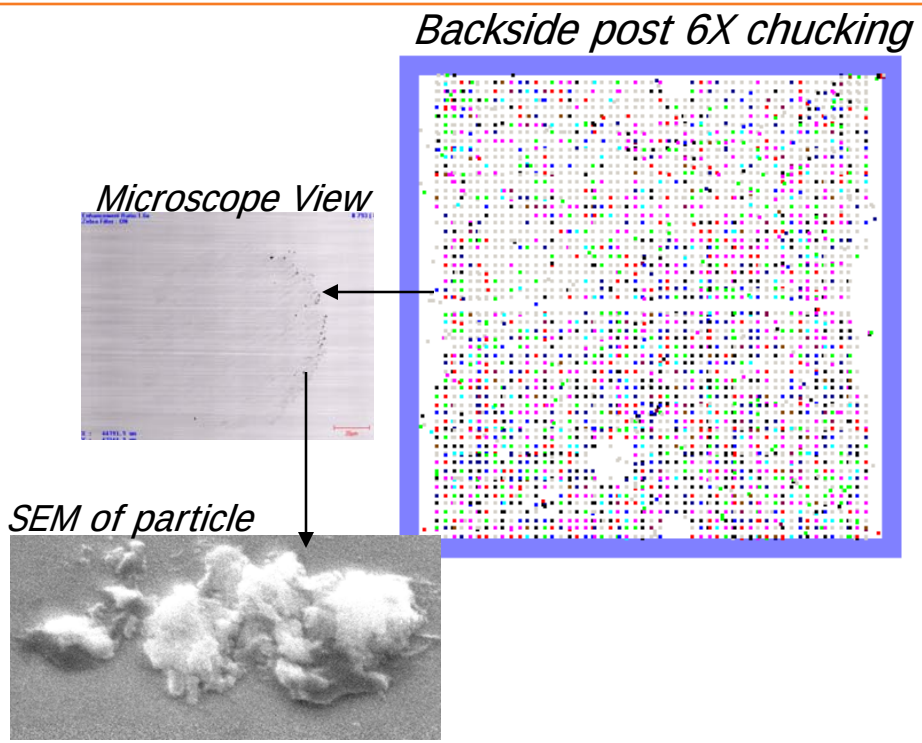
Pre Shipping

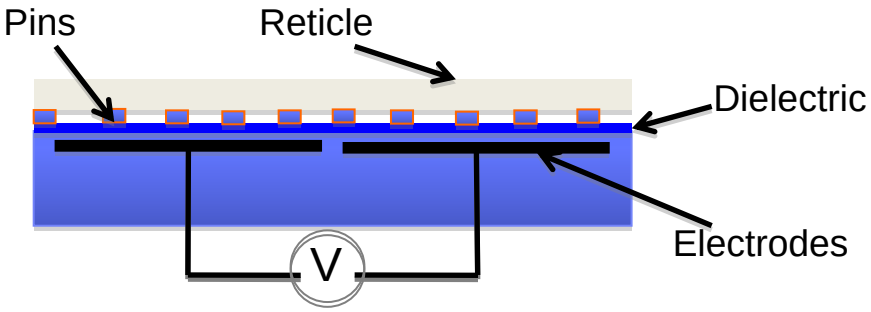


Post ADT Handling +Shipping

Backside Inspection: After 6X Chucking

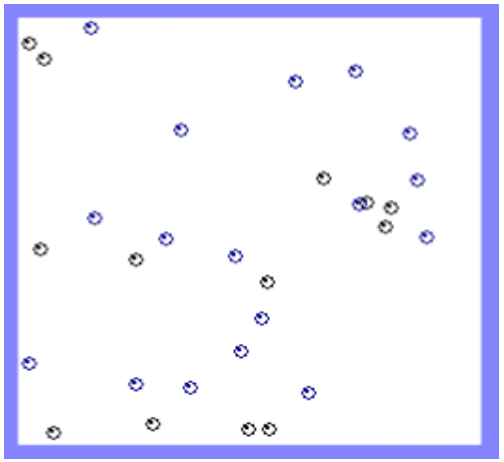
- ADT chucking damages the CrN backside film
- Most pin-mask contact points have damage
  - Detection ring of ~50um radius
  - Damage-free strip is separation between electrodes
- Composition of defect
  - Organic
  - Details under analysis
- Cleaning of defects
  - Multiple cleans cannot remove all particles



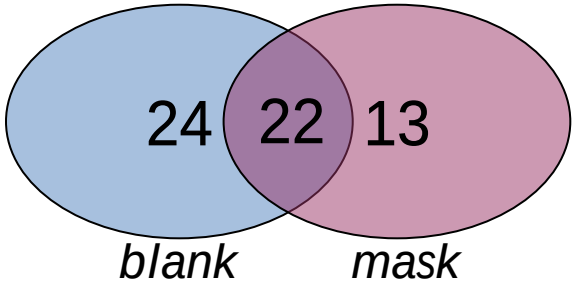


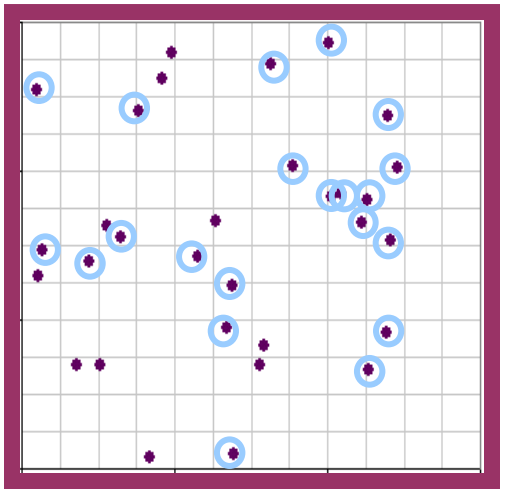
Initial Front Side Inspection

- Initial blank inspection
  - Minimum defect ~60nm
  - 46 defects
- Patterned inspection
  - 35 defects
- Good but not perfect match
  - 22 defects transferred
  - 13 new defects
  - 24 did not transfer



Blank Inspection
before Resist Coat

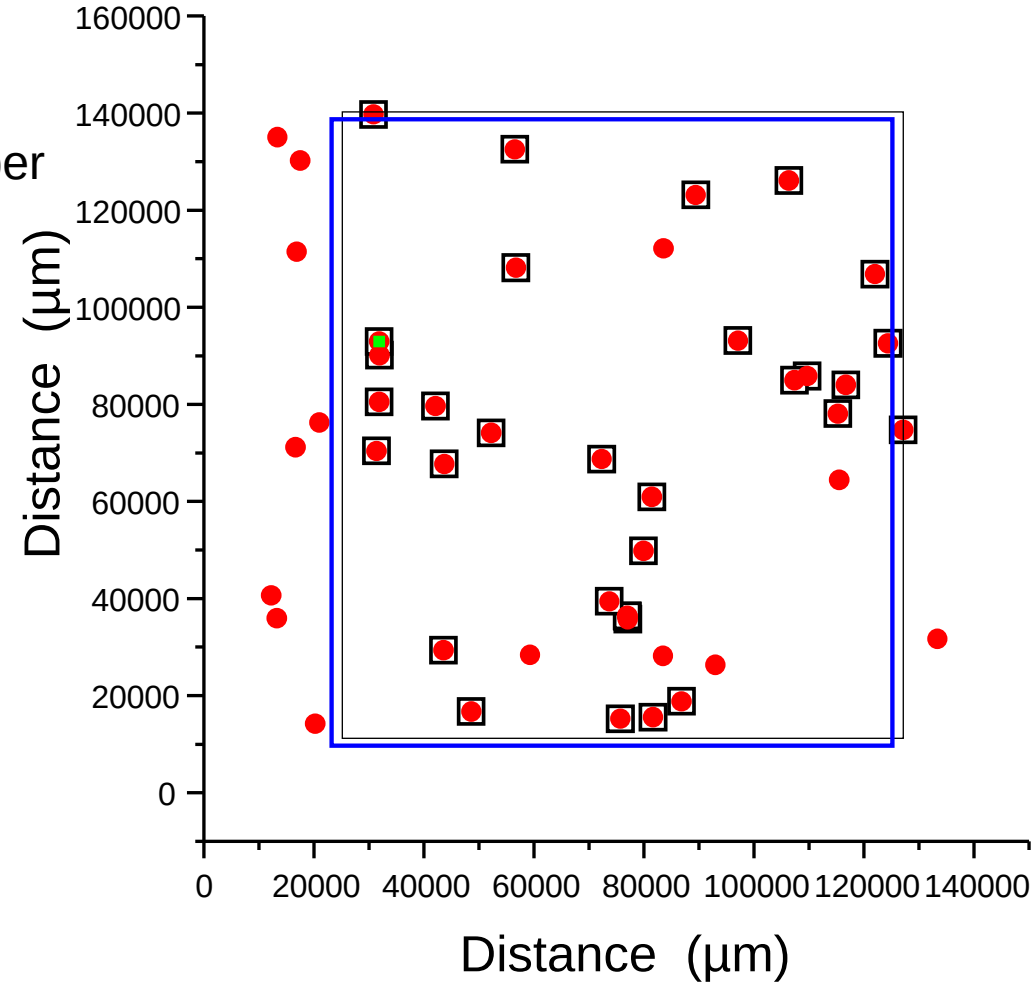




Patterned Mask Inspection
before Shipment

Some Blank Defects Mitigated by Absorber

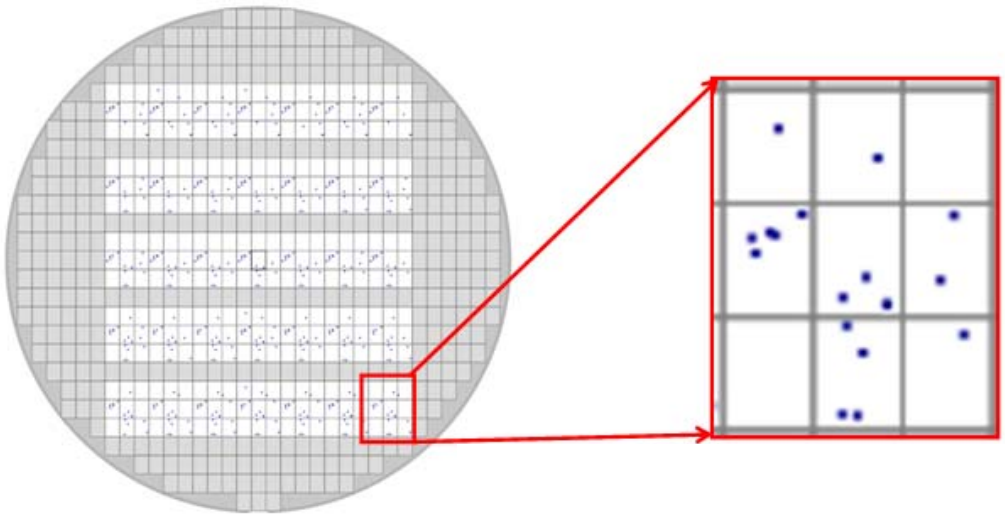
- Blank defect statistics
  - 46 total blank defects
  - 11 defects fall under absorber
  - 8 additional defects can be hidden by pattern shift
  - 27 remaining defect are too large to hide



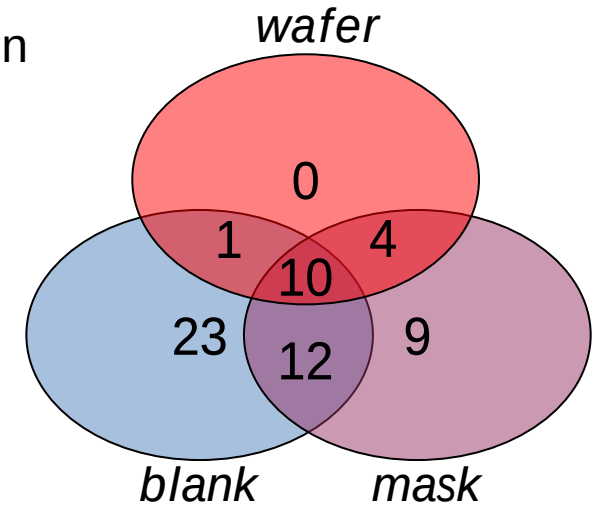
Printing Defects
All Defects
Small Defect
Patterned Area
Shifted Area

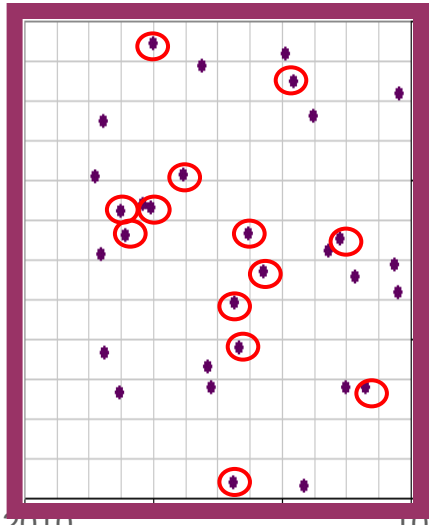
Initial Wafer Inspection

- Inspection from exposed wafer shown
  - Minimum defect size ~ 25nm on wafer (100nm on mask)
- Result:
  - 15 wafer repeating defects
  - 14 of these detected at mask inspection
  - Remaining defect was detected on blank, but not on mask
- Next step: multiple load/un-load cycles



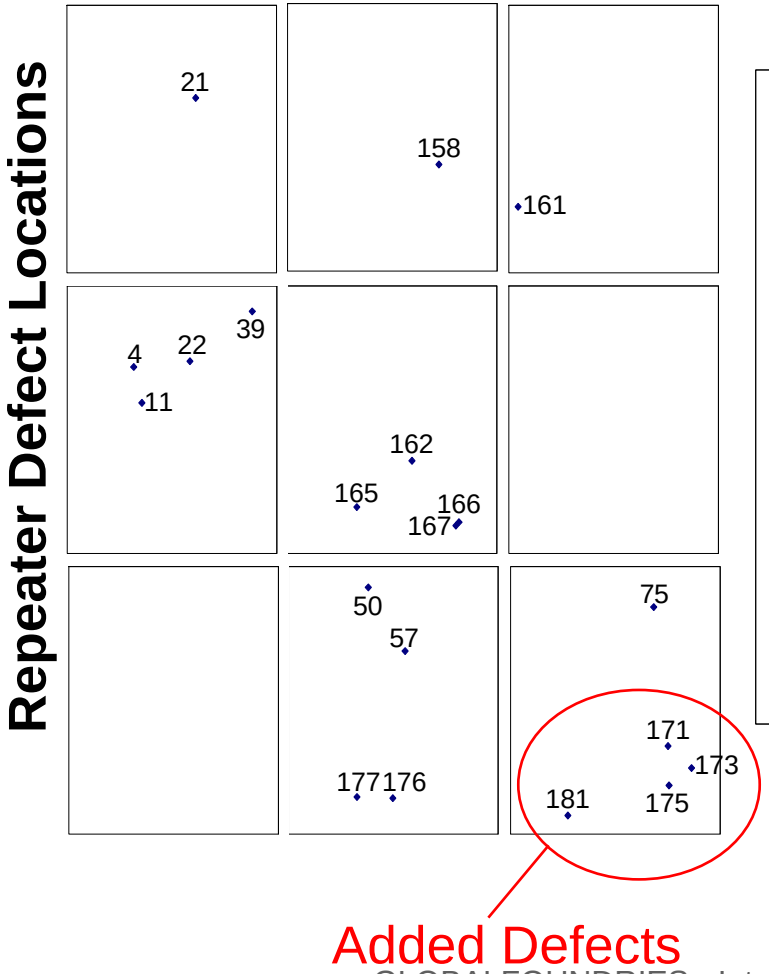
Patterned Mask Inspection
before Shipment

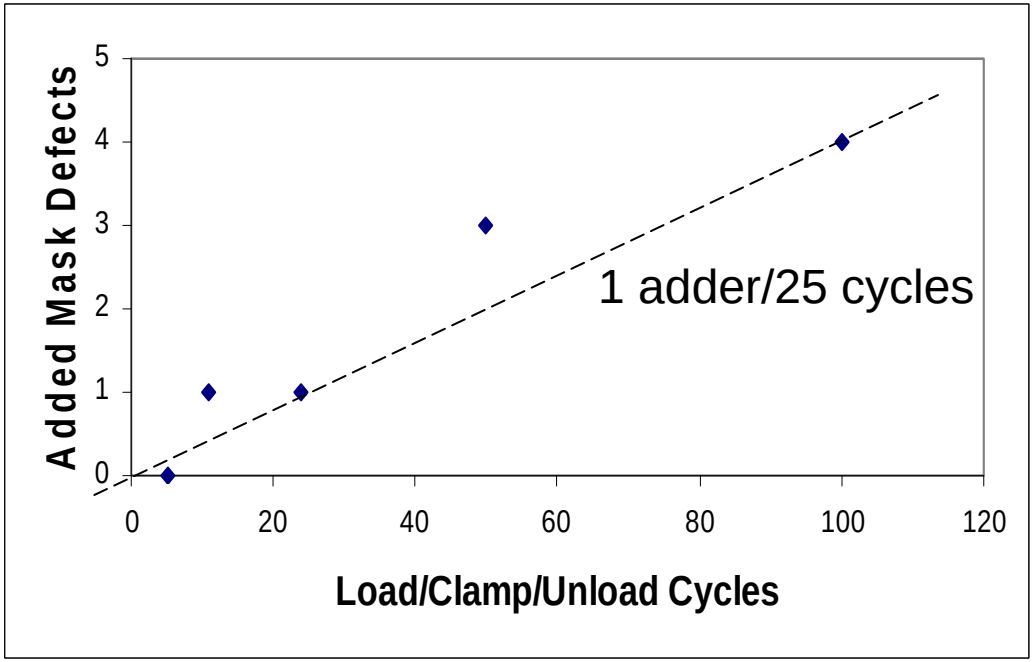




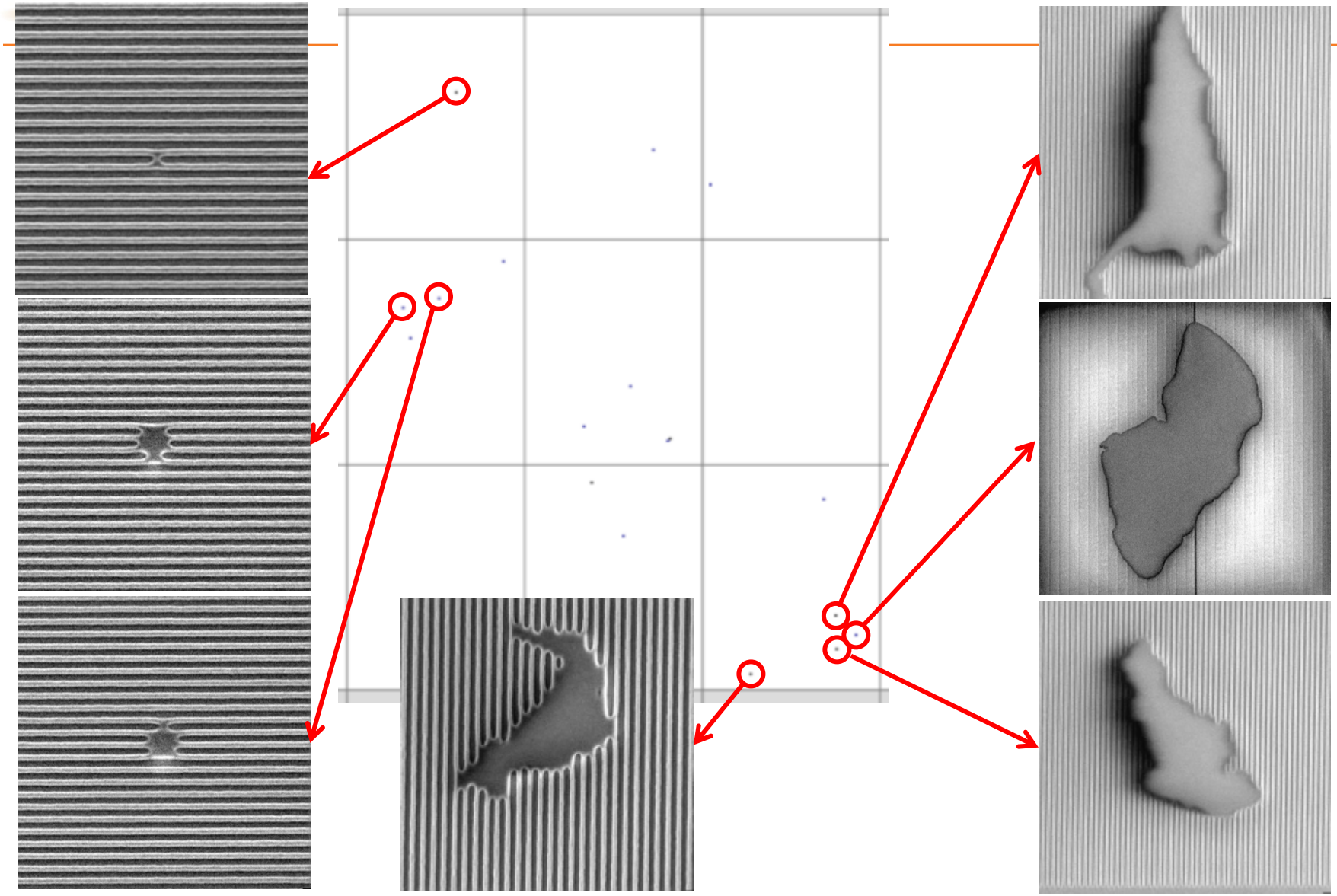
Wafer Inspection after 100 Load/Unload Cycles

- **On average 1 defect is being added to the frontside of the reticle for every 25 load/clamp/unload cycles through Albany ADT**



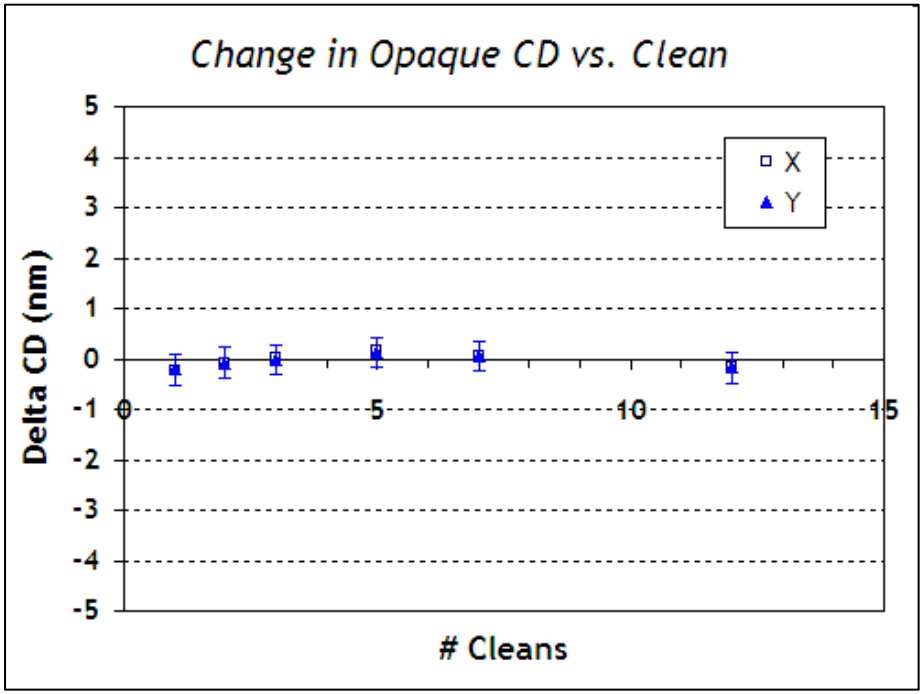


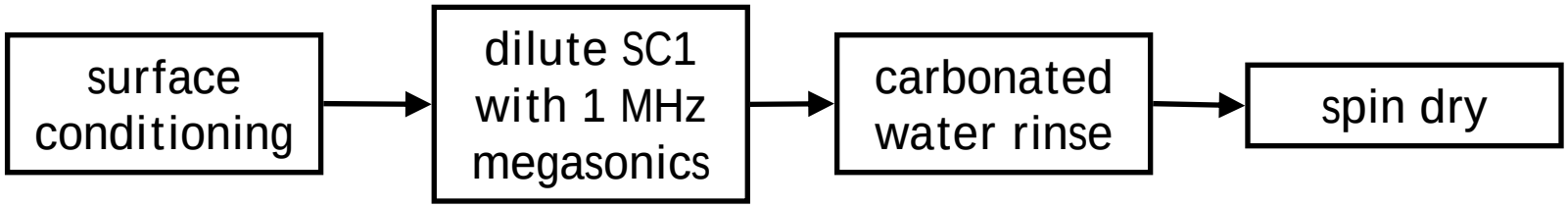
Examples of Repeater Defects



EUV Mask Clean – Impact on CD

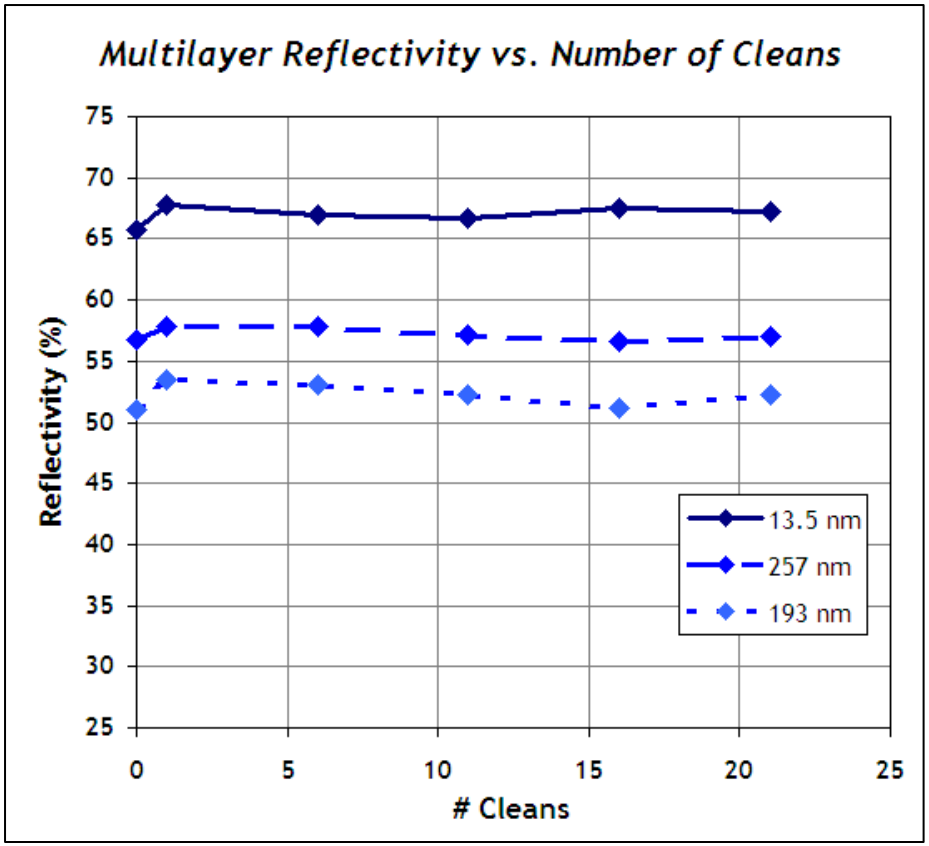
- Goal: Test clean developed for EUV films
- Method: EUV patterned test mask measured for CD loss on Ta absorber
  - 200nm line data
  - X and Y
  - 200-site average
- *Result: Negligible change in CD after 12 cleans: <~0.1nm/clean*





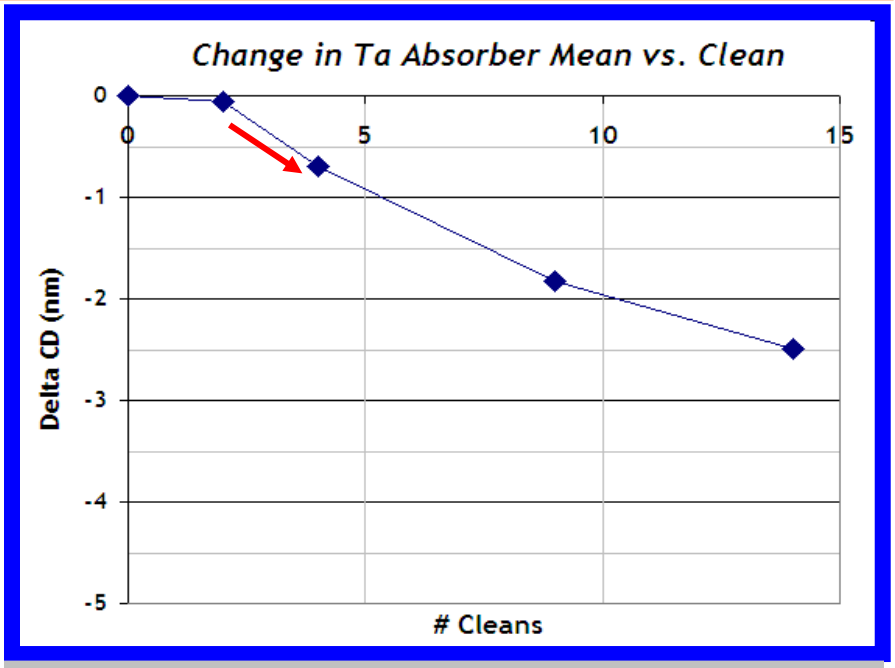
EUV Mask Clean – Impact on Reflectivity

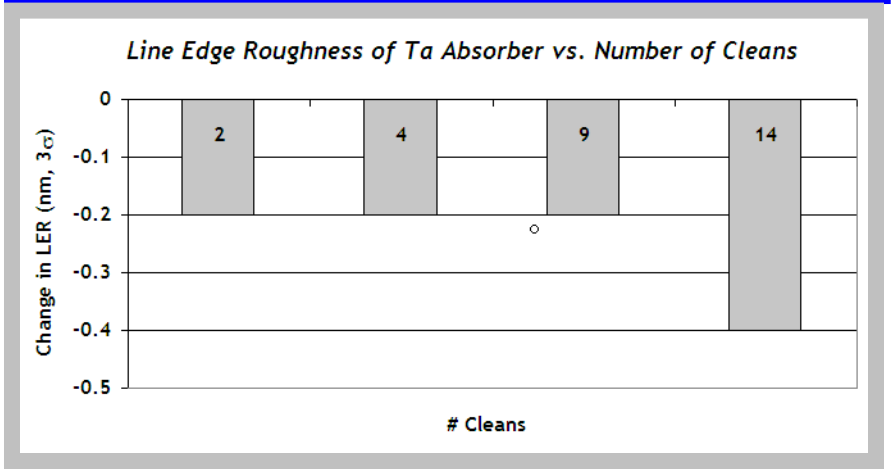
- Goal: Measure change in reflectivity of Ru-capped ML after clean
- Method: EUV and inspection wavelengths measured after cleans
- Results:
  - Initial increase observed in reflectivity at all monitored wavelengths
- *EUV reflectivity on Ru-capped ML does not change after >20 cleans*



EUV Mask Clean – Impact on LER

- Change in CD mean plotted as a function of cleans
  - 112nm opaque, 15-site average
  - 0-2X CD change <0.1nm/clean
  - After aggressive clean removal rate is ~0.5nm/clean
  - *CD loss rate is increased by the aggressive clean*
- Change in LER plotted as a function of cleans
  - *LER improves with standard EUV clean*





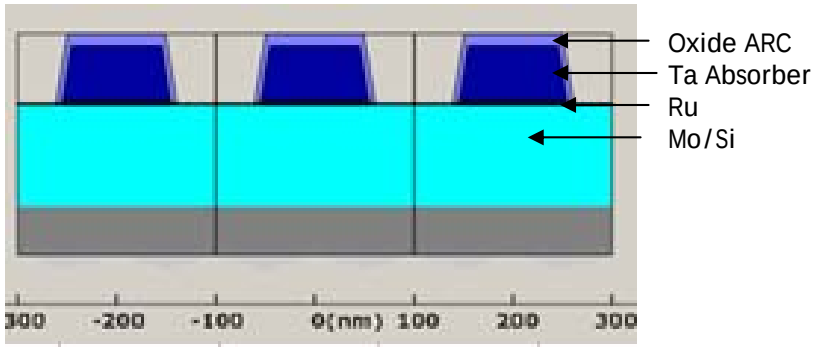
Effect of Cleans on Surface Quality

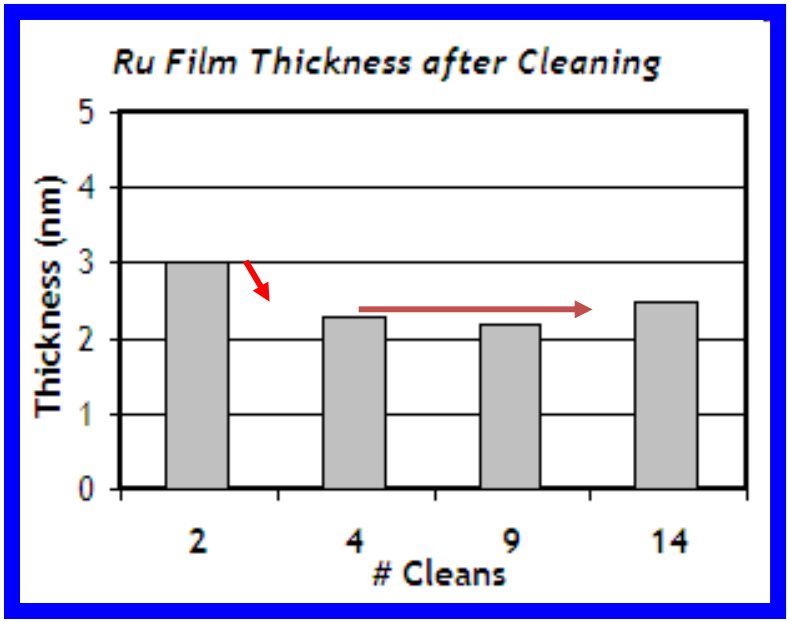
- Quantified change to Ru-capped multilayer surface
- Reflectivity
  - Measured prior to exposure and after 2X exposure and 14X clean
  - *EUV reflectivity is ~ unchanged*
- Roughness
  - Measured prior to exposure and after 2X exposure and 14X clean
  - *Mask roughness is reduced*

	EUV R (%)	Centroid (nm)	Roughness RMS (nm)
initial	**63.4**	**13.53**	**0.31**
post exposure/clean	**63.3**	**13.53**	**0.21**

Mask Scatterometry

- Scatterometry: non-destructive method for obtaining profile and film data
  - Model goodness of fit: 0.994
  - Model precision CD: 0.972
  - Model precision SWA: 0.506
- Enables film measurements on production mask
  - Measured after 2, 4, 9 and 14 cleans
- *Negligible Ru cap loss with optimized clean*





Summary

- ASML ADT reticle clamp damages the CrN backside film
  - Multiple cleans cannot remove all backside particles
  - Backside particles do not move = minimal risk of cross contamination
- ASML ADT adds very few patterned surface defects
  - 1 defect is added for every 25 load/clamp/unload cycles, on average
- Effective mask clean has been developed for EUV
  - Minimal change in CD and decrease in LER with standard EUV clean
  - Negligible reflectivity loss and improved RMS roughness
- Estimated Mask Lifetime in the ADT:
  - EUV mask must be removed every 4 – 6 hours to prevent buildup of charge on the ADT reticle clamp
  - Since 25 reticle loads are possible before 1 particle is added, an ADT mask will need to be cleaned every 100 – 150 hours (4 – 6 days)
  - Since > 20 cleans are possible before a significant change in mask CD, EUV mask lifetime in the ADT could be as long as 3 – 4 months.

Acknowledgements

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