Complex Shape EUV Extreme-Ultraviolet Patterning : EUV Resist Process Optimization and Dry Etch Solutions for Defect Reduction and Cross-Wafer Uniformity Improvements

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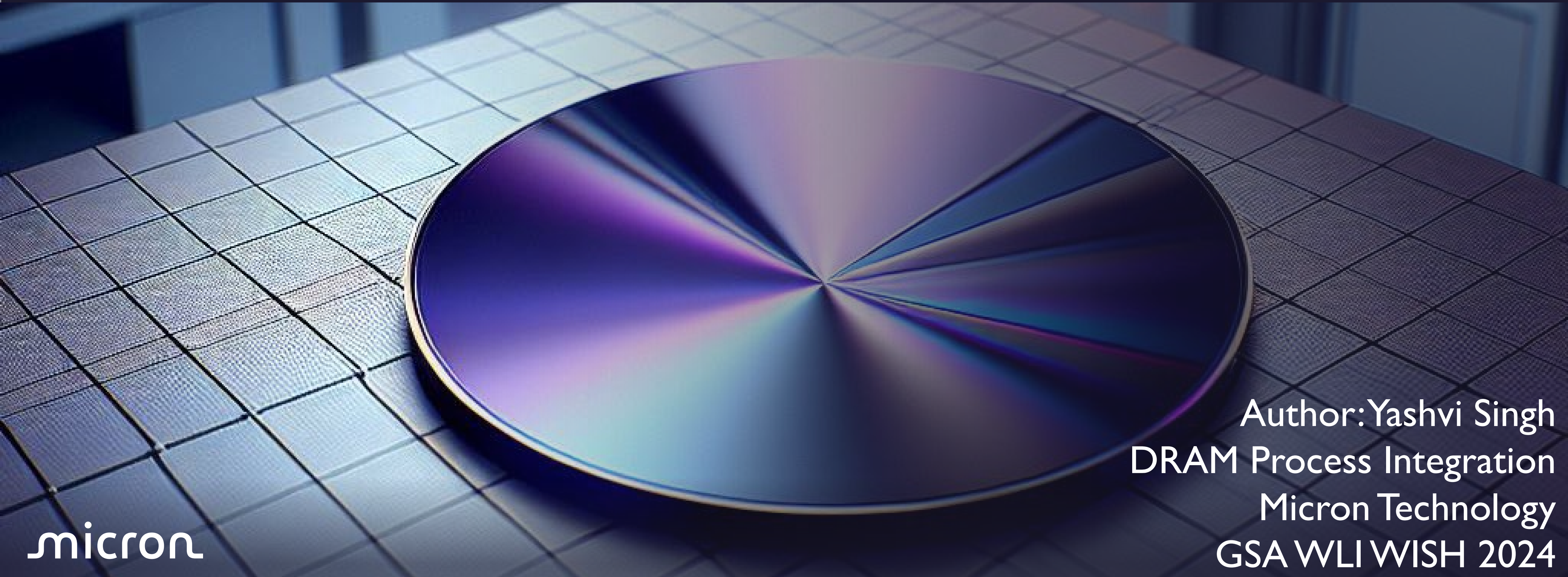

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DRAM Process Integration

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GSA WLI WISH 2024

Agenda

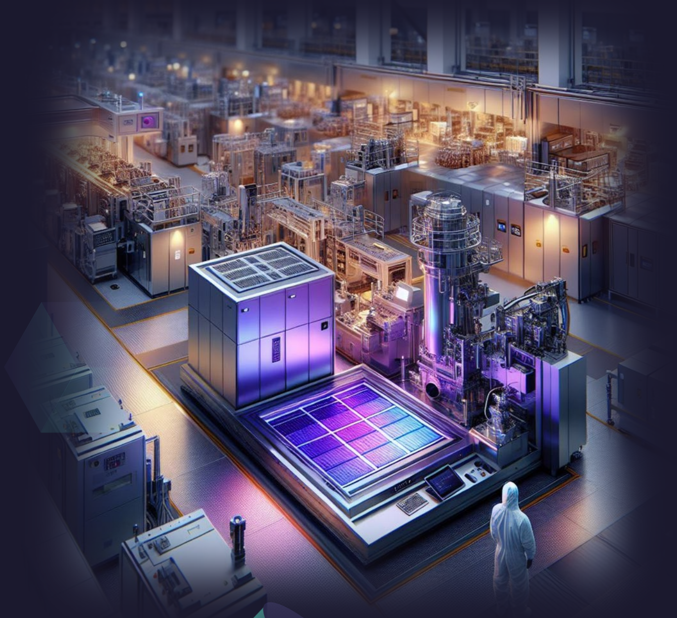
A. Introduction

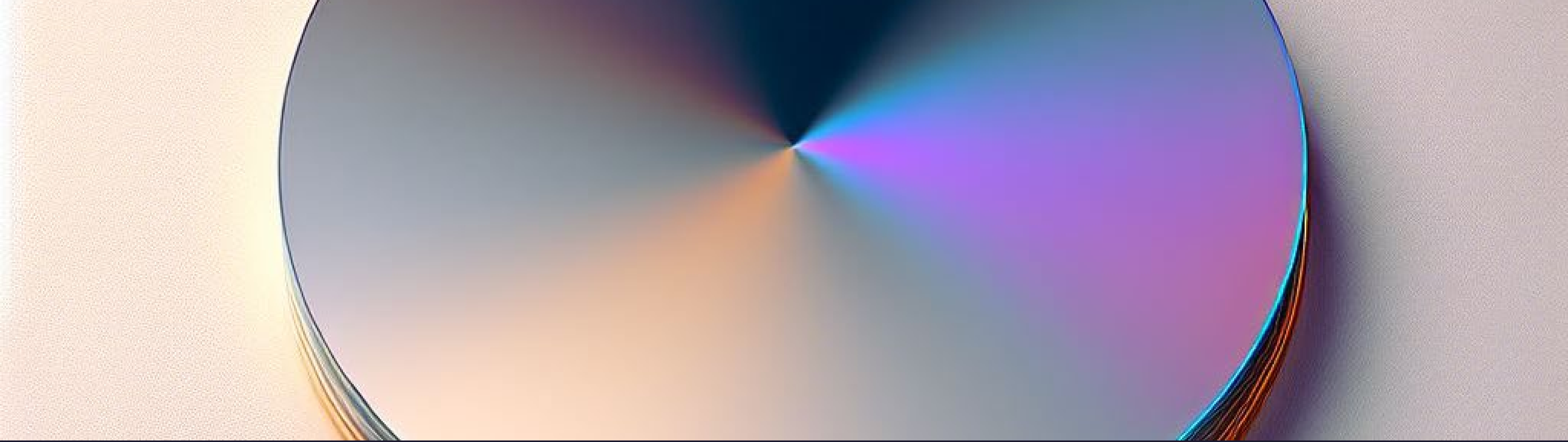
B. Defect Reduction in Complex Patterns through EUV Track Developer Optimization

C. Dry Etch Optimization and Uniformity Tuning for Complex EUV Pattern

- Mechanism 1
- Mechanism 2
- Mechanism 3

D. Conclusion





Importance of Surface Area For Semiconductor Devices

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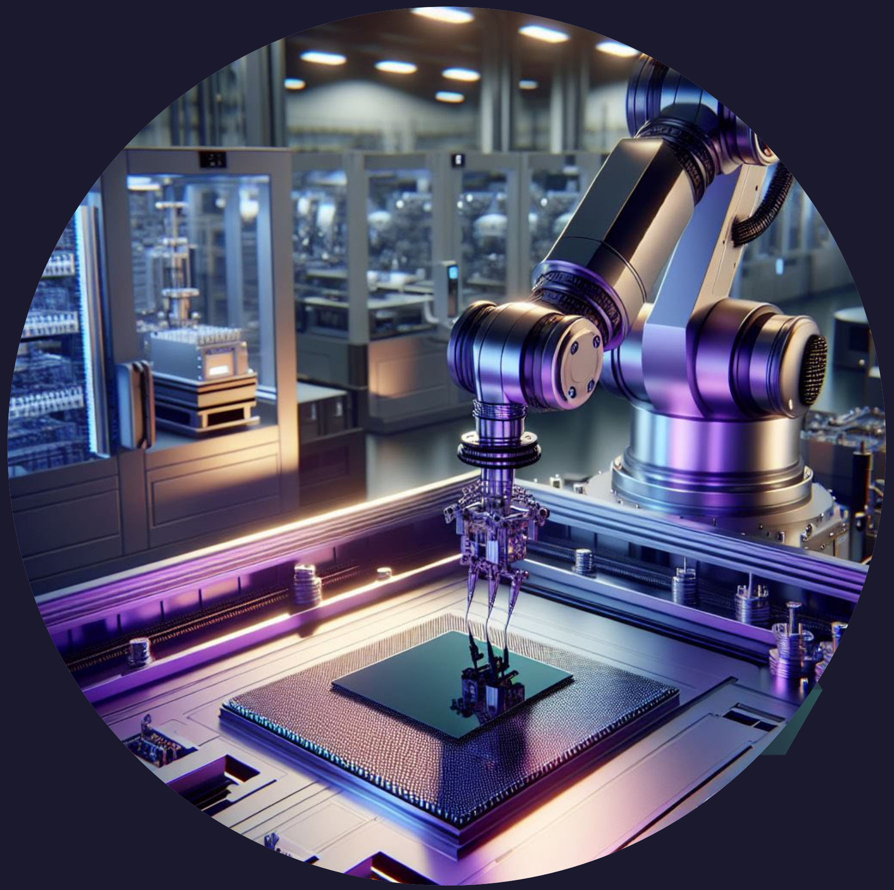
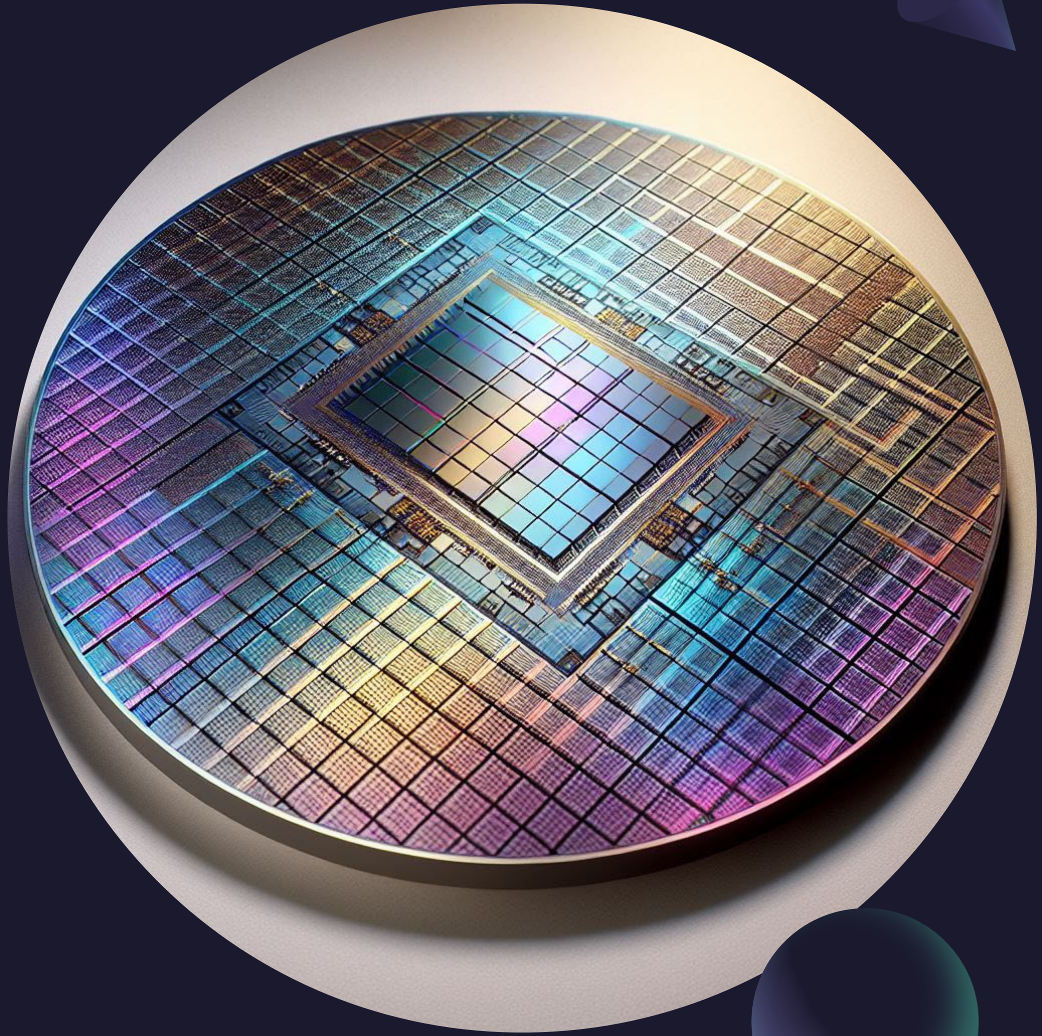
Large surface area	Higher device density	Higher Computational Capabilities
Flat surface	Photolithography accuracy	Better device functionality and reliability
Surface quality	Etching control	Better device functionality and reliability
Smooth surface	Minimizes Contact Resistance	Improves Signal Transmission
Low surface irregularities & contamination	Defect minimization	Better performance and quality



More Complex Patterning Solutions are needed for delivering memory needs of the Future



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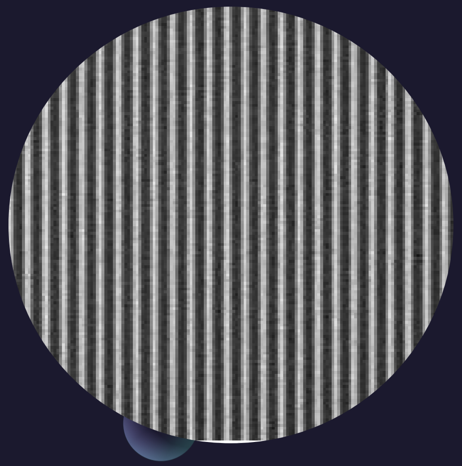
Must overcome Drawbacks of current EUV Lithography and Dry Etch Technology to provide solutions for Complex Patterns sub 10 nm pitch

Traditional Line and Space Pattern



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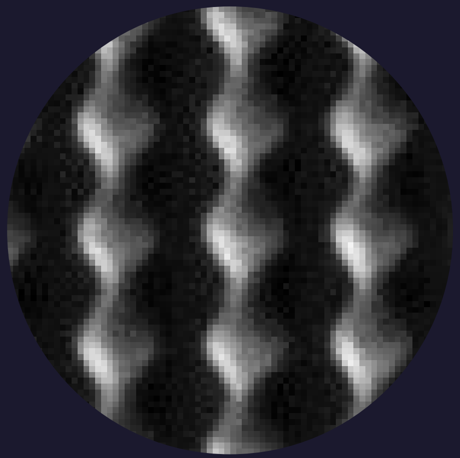
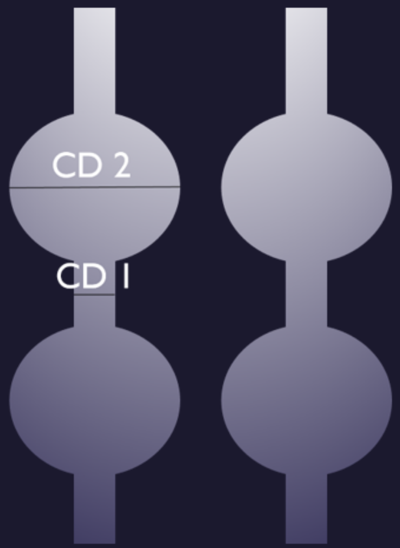
Complex Pattern: Combination of Rectangular and Spherical Geometry



Novel Complex EUV Pattern

CD 1 = line CD
CD 2 = spherical curvature CD
CD 3 = CD 2 – CD 1



CD= Critical Dimension

Key Solutions For Defect Reduction and Cross-Wafer Uniformity: EUV Resist Process Optimization and Dry Etch Solutions

CD : Critical Dimension

Defect Reduction in Complex Patterns through EUV Track Developer Optimization

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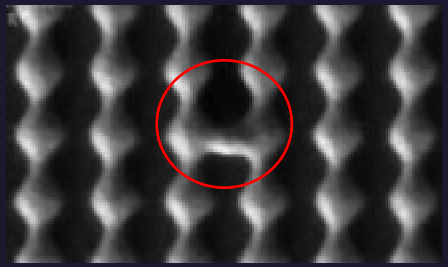
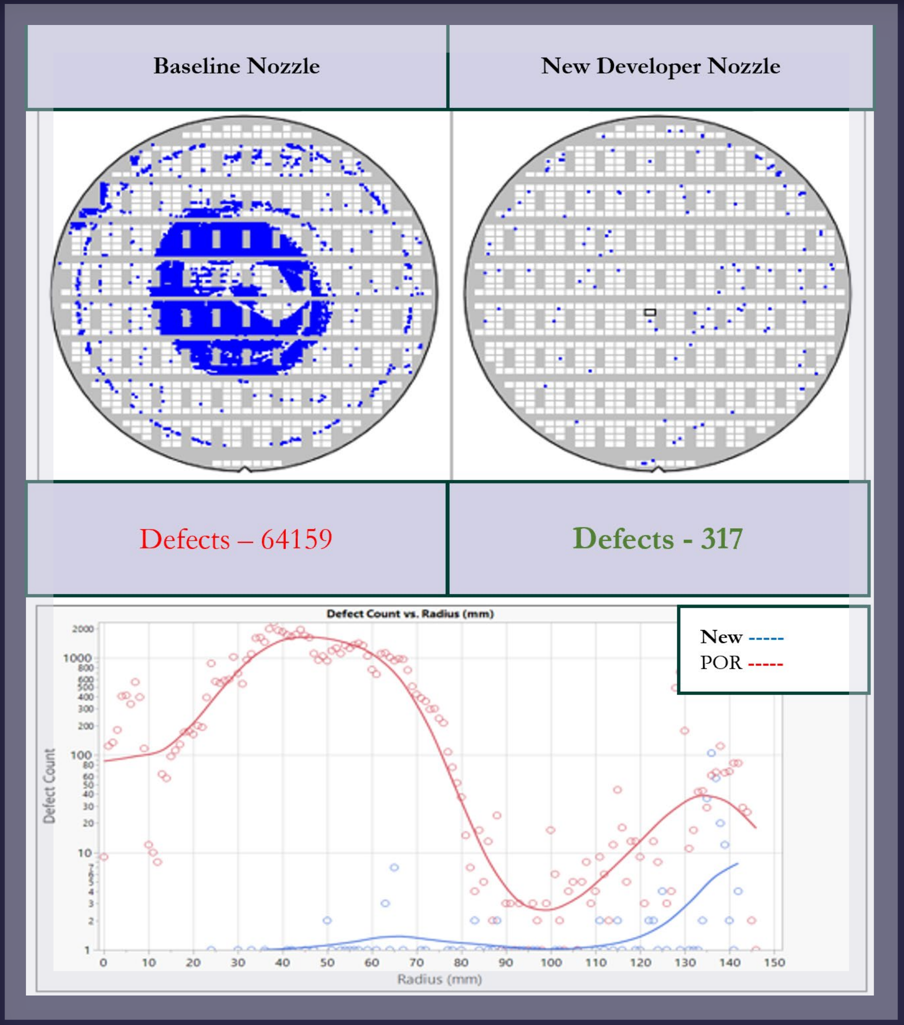
Problem Statement

Conventional Nozzles lead to heavy center-of-wafer (CoW) bridging defects. The complex pattern is very sensitive to developer flow dynamics at the litho step, leading to lower resist scumming margin and consequently blocked etch



Post Hardmask Etch Transfer CoW Bridging Defects

“New Developer Nozzle” for Positive Tone Developer (PTD) was a breakthrough to Significantly Improve Defectivity (100% to < 1%)



Conventional-1 Dynamic Process :

1) Higher liquid flow on wafer

2) Less Developer consumption

Conventional-1 Static Process :

1) Less liquid flow on wafer

2)Higher developer consumption (100 ml- 200 ml at PTD)

“New Developer nozzle” (combination of dynamic and static process)

1) No center signature

2) Less developer consumption

Process Flow of "New Developer Nozzle"

Parameters Optimized in "New Developer Nozzle"

Conventional & NDNozzle

- **Pre-Wet** : Minimize time difference in the initial application of developer solution

"ND"nozzle

- **Puddle Formation** : Formed with lower spin speed application; CD Profile is controlled with scan process

"ND"nozzle

- **Puddle** : Process enables uniform resist development across wafers

CD : Critical Dimension

Developer parameter

- Developer evenly distributed across wafer; spin time & spin speed is increased.

Addition of Dynamic Puddle

- More developer reaction time added to infiltrate the hole pattern.

Defect Reduction Rinse Control

- Spin speed during scan rinse made same as centrifugal force which helps EUV resist to maintain hydrophobicity

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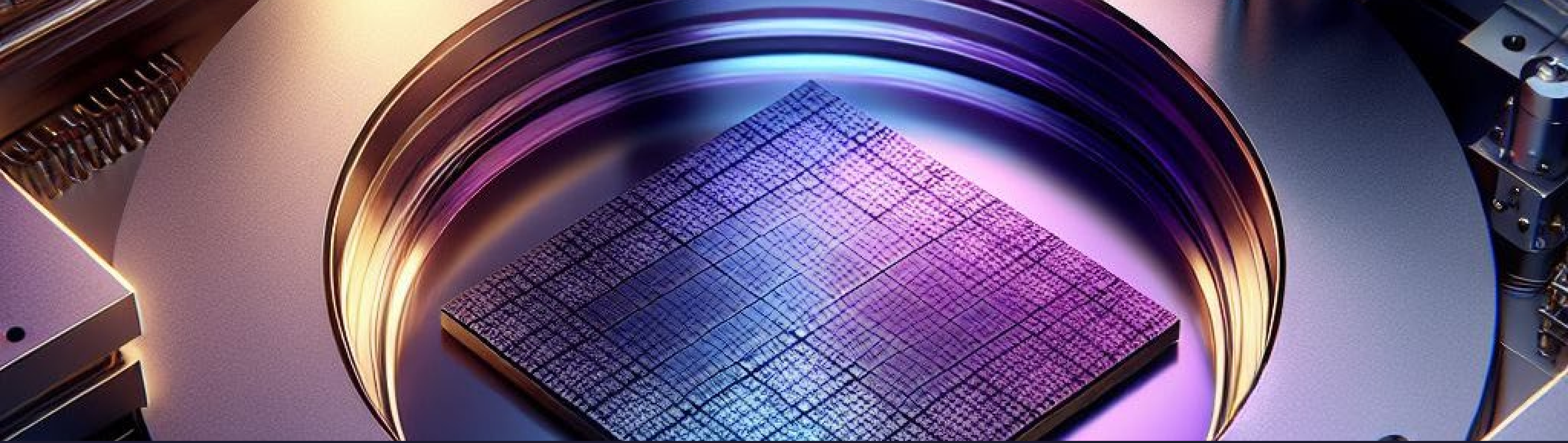


Dry Etch Optimization and Uniformity Tuning for Complex EUV Pattern

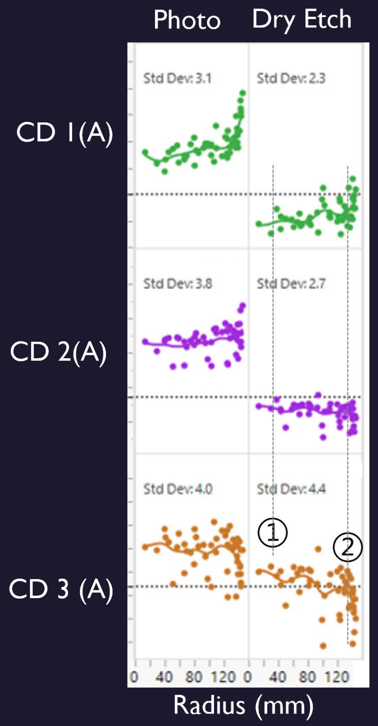
Challenges In Etching Complex EUV Pattern

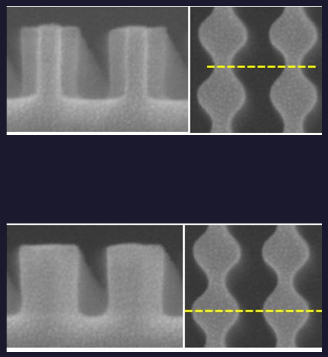
Aspect Ratio Dependent Etch (ARDE)

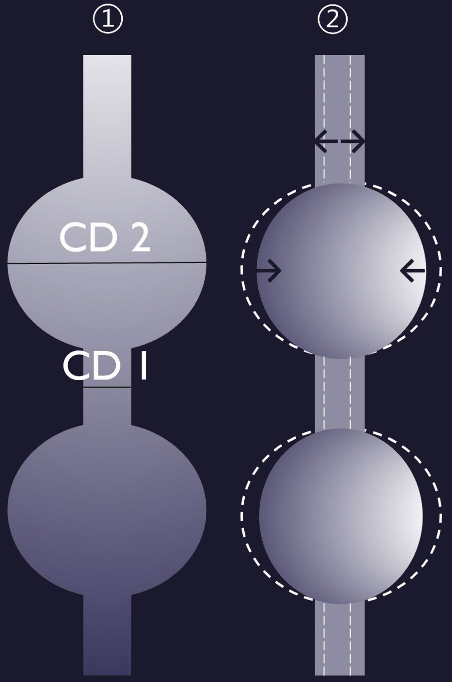
Ion Reflection Effect

Cross Wafer Loading Effect

Edge Roll-off due to Tapered Resist



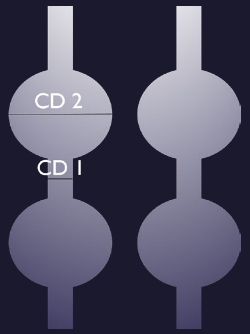




Dry Etch Industry-wide Tuning Parameter	Novel Dry Etch Tuning Parameter
Cannot Independently Control CD 1 and CD 2	Independent control CD 1 and CD 2
Electrostatic chuck (ESC) Temperature, Inductively Coupled Plasma Etching, and Gas Injection	**Discover New Parameters**

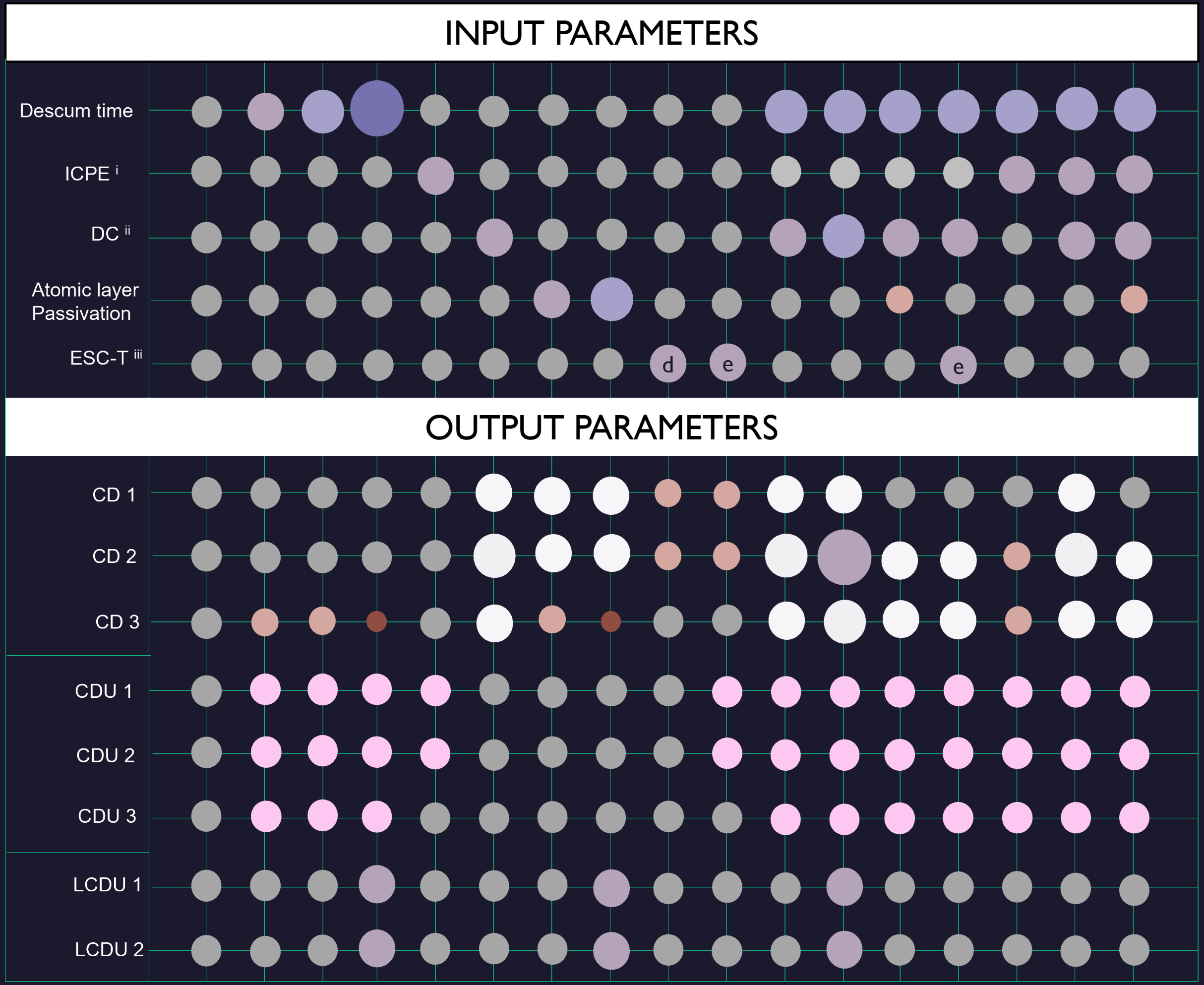
CD 2 erodes faster than CD 1 causing high CD 3 loss (CD 3 = CD 2 – CD 1), i.e., lesser overall surface area), especially at the wafer edge

Solution: Descum Step (DS) is the Main Parameter to enable good uniformity of CD 3 from wafer center to edge



CD3=CD2-CD1

Dry Etch Parameters Design of Experiment (DOE)



Effect of novel tuning parameters identified on CD (critical dimension), CDU (critical dimension uniformity) and LCDU (local critical dimension uniformity) of features 1, 2 & 3

i Inductively coupled plasma etching
ii Duty Cycle
iii Electrostatic Chuck temperature
1 feature
2 feature
3 feature
d 4-Zone Sync adjustment
e 4-Zone out of sync adjustment

- -- decrease
- - decrease
- some change
- standard condition/no change
- + increase
- ++ increase
- +++ increase

Main parameters under Descum Step

- Descum Time
- N_2/CH_2F_2 gas flow rate
- RF Pulsing Duty Cycle

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Mechanism 1: Descum Time impact on CD 3

Descum time is the key step for tuning CD 1 and CD 2

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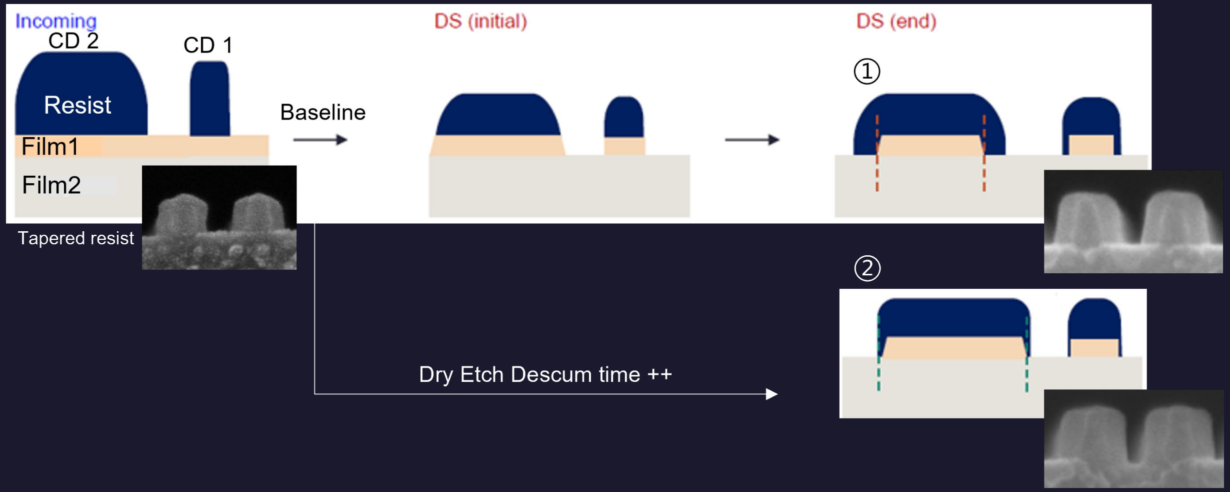

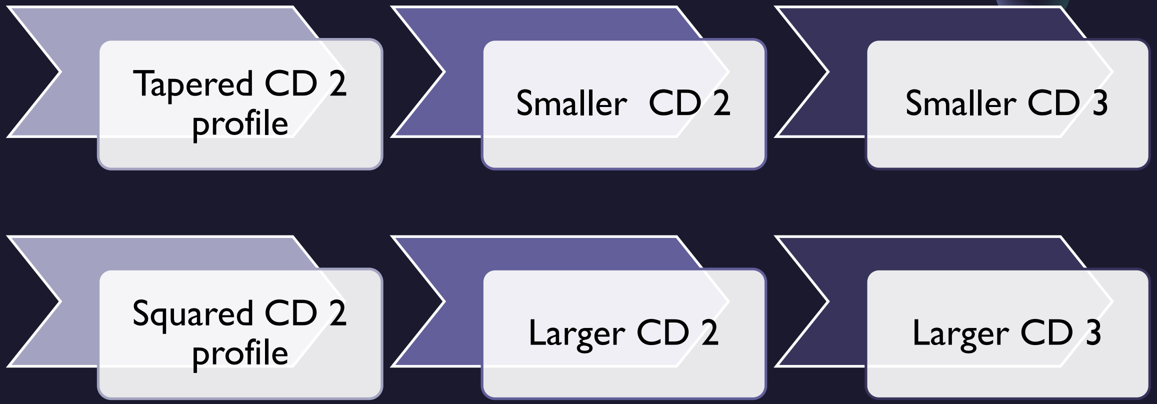

SEM data of incoming EUV Resist profile and Etch Movie at wafer edge

Angle of CD 2	Baseline	Longer Descum Time	Delta [a]
Incoming Photo Resist	119.1°		
Post 1st phase Film1 Dry Etch	101.9°	94.1°	7.8°(↓)
Post 2nd phase Film1 Dry Etch	97.3°	92.3°	4.9°(↓)
Post Film2 Dry etch	94.8°	90.5°	4.3°(↓)
Post Full Dry Etch	89.9°	90.2°	0.3°(~)

a: Delta CD 2 for POR and Longer Descum Time, ↓: Improved, ~: Comparable

Longer descum makes dry etch profile straighter by ~5° on the hard mask and underlayer mandrel, preventing mask erosion of CD 3

Larger CD 2 and CD 3 : lean fluorine etch chemistry and more polymer deposition

Lean fluorine chemistry helps minimize Film1 lateral etch during mask open step

More polymer deposition enables squared profile of resist and Film1, even with tapered incoming resist profile

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Mechanism 2: Cross wafer CD 3 CDU improvement through Descum Time

Sufficient Descum Time provides more polymer deposition to protect resist and mitigate wafer edge non-uniformity

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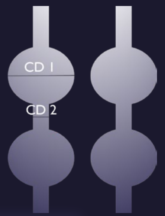
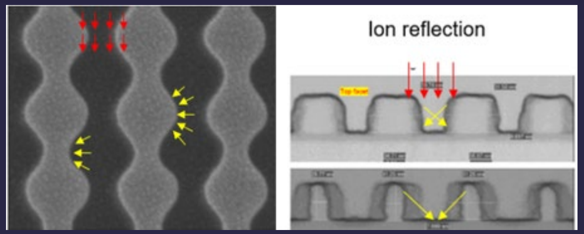
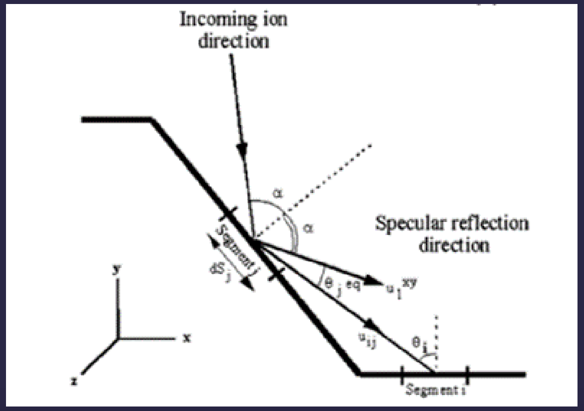
CDU : Critical Dimension Uniformity

Tighter spaces between CD 2 experience enhanced ion reflection effect which causes higher CD degradation of feature 2, decreasing overall surface area







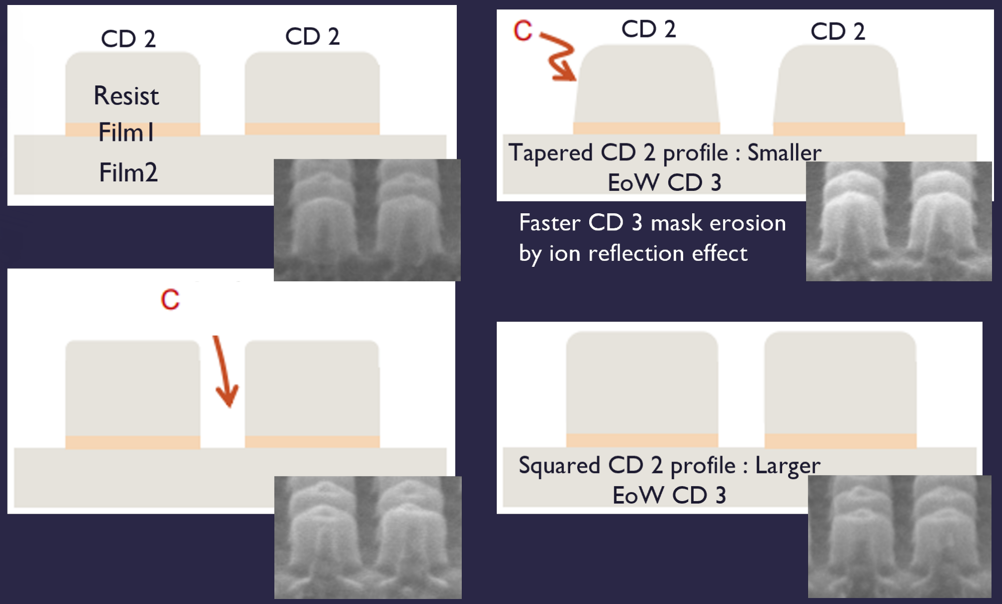
Incoming and reflected ion fluxes for the sidewall of a trench, projected to x–y plane

Center of Wafer (CoW)

Edge of Wafer (EoW)

Shorter descum time
Less polymer deposition

Sufficient descum time
Optimized polymer deposition



Sufficient descum time provides more deposition to protect resist and mitigate wafer edge nonuniformity, thereby increasing surface area even at wafer edge

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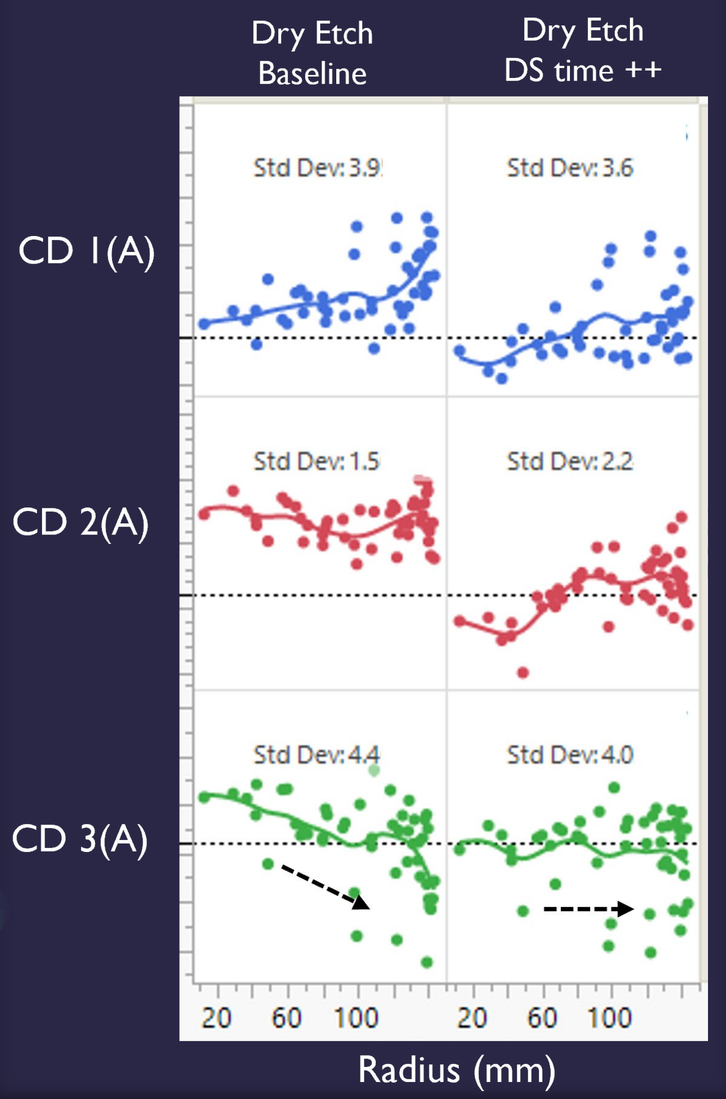
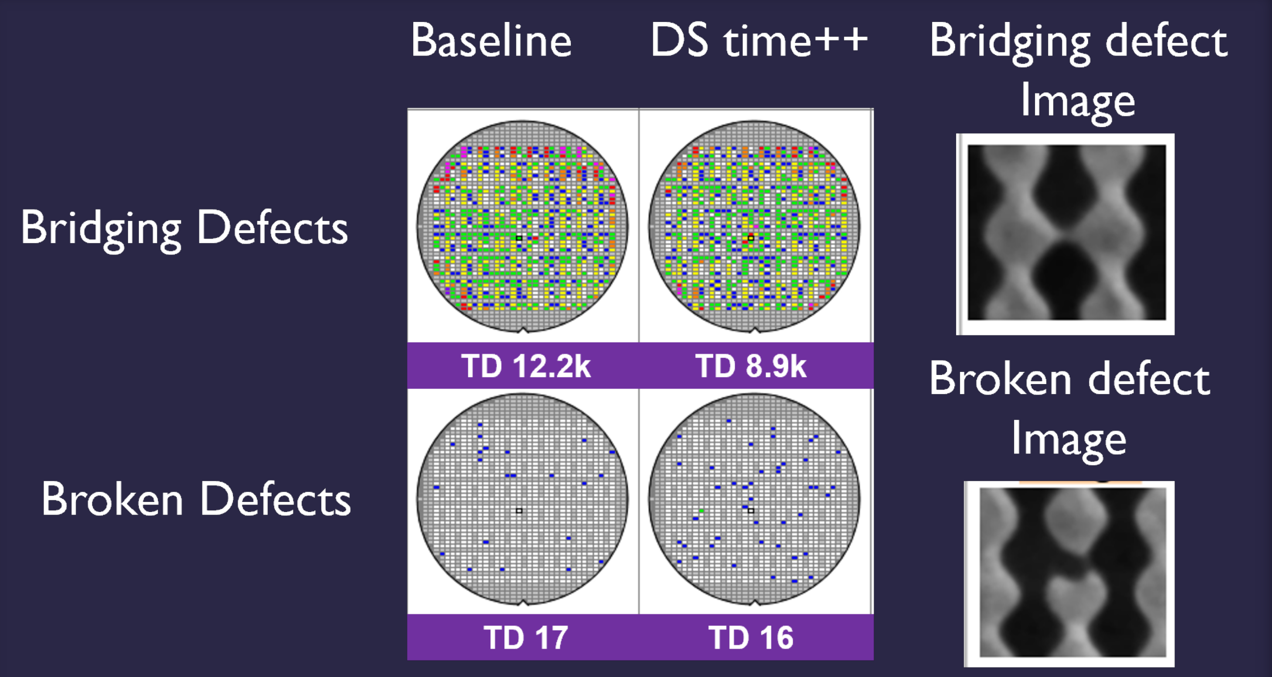
CD & Defect count vs Descum time skew





Sufficient descum time improves CD 3 uniformity and reduces bridging defects

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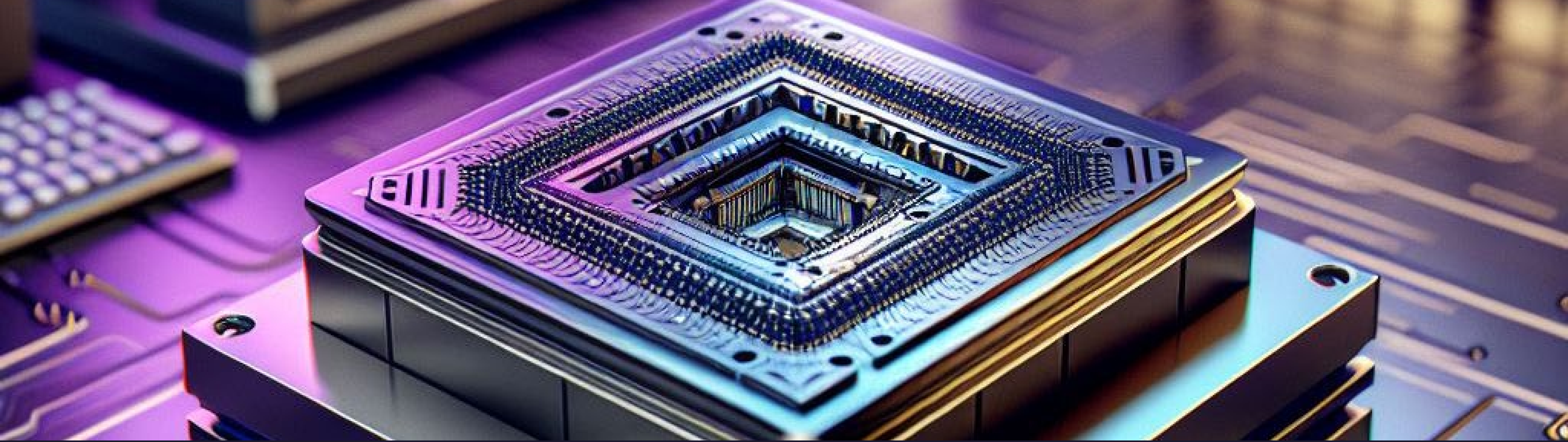

Mechanism 3: CD 3 Local CDU Optimization through Polymer Deposition Tuning

CD and LCDU metrics improved with Gas Flow Rate, RF Pulsing Duty Cycle and Trim Time adjustments at Descum and Trim steps

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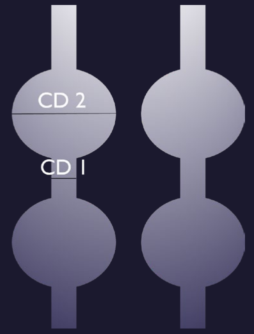
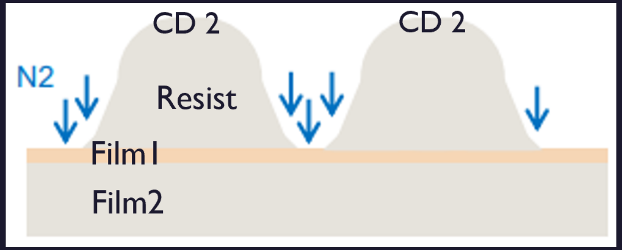
LCDU : Local Critical Dimension Uniformity

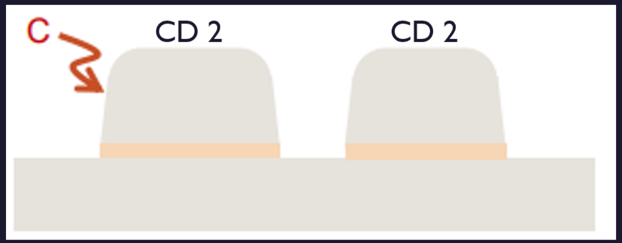
Impact of Polymer Deposition on CD 2 Profile



CD3=CD2-CD1

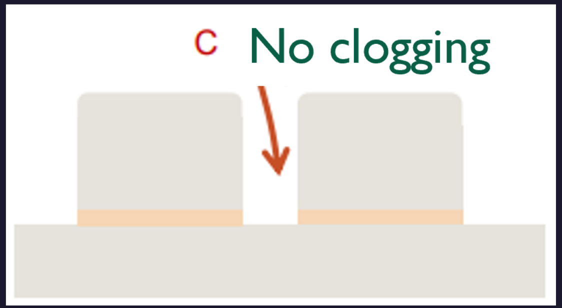
Incoming resist
Tapered and footed profile





Case 1: Insufficient descum time
Less polymer deposition

Case 2: Sufficient descum time
Optimized polymer deposition



Case 3: Longer descum time
Saturation of polymer deposition

Longer Descum Time does not impact profile and has no byproduct clogging

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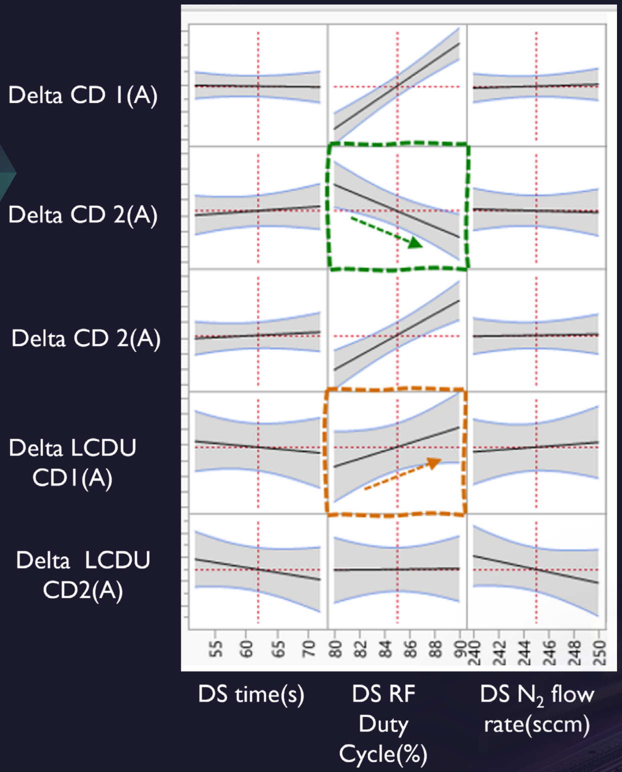
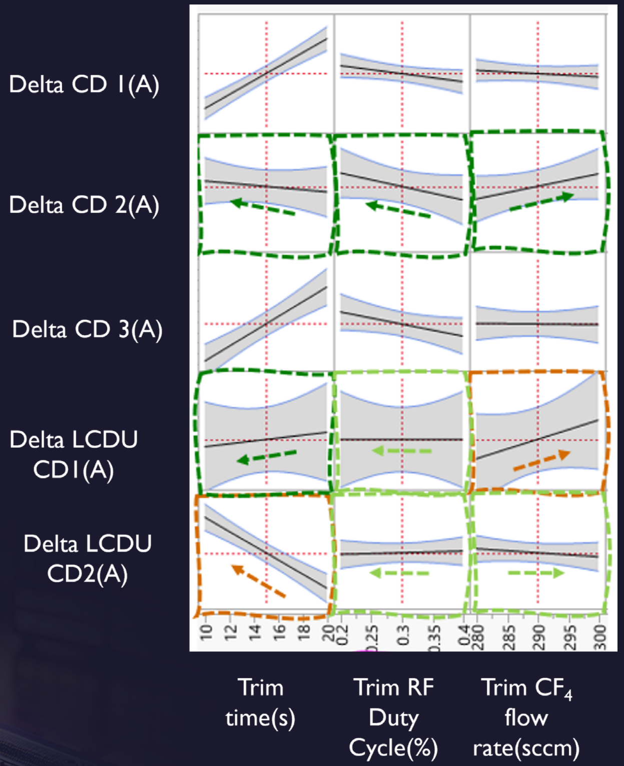
Methodology : Key Parameters affecting CD 3 LCDU

DOE Prediction Profiler of DS step and Trim Step
(Delta: Resist CD minus post etch CD)

Source	Log Worth	PValue
DS Duty Cycle	3.273	0.00053
Trim time	3.032	0.00093





Sufficient Descum Time

- Good Cross wafer Profile
- CANNOT optimize LCDU
- No clogging

Longer Descum Time

- Good Cross wafer Profile
- CAN optimize LCDU
- No further clogging

P1 DS Radio Frequency (RF) Pulsing Duty Cycle

P2 Trim Time & Trim Pulsing Duty Cycle

P3 N_2/CH_2F_2 gas flow rate adjustment in descum step

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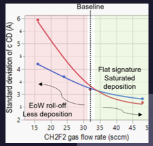
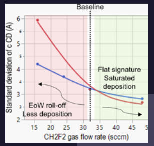
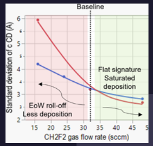
CD, LCDU & Defectivity Impact with DS N_2 /CH_2F_2 Gas Flow and Trim Time



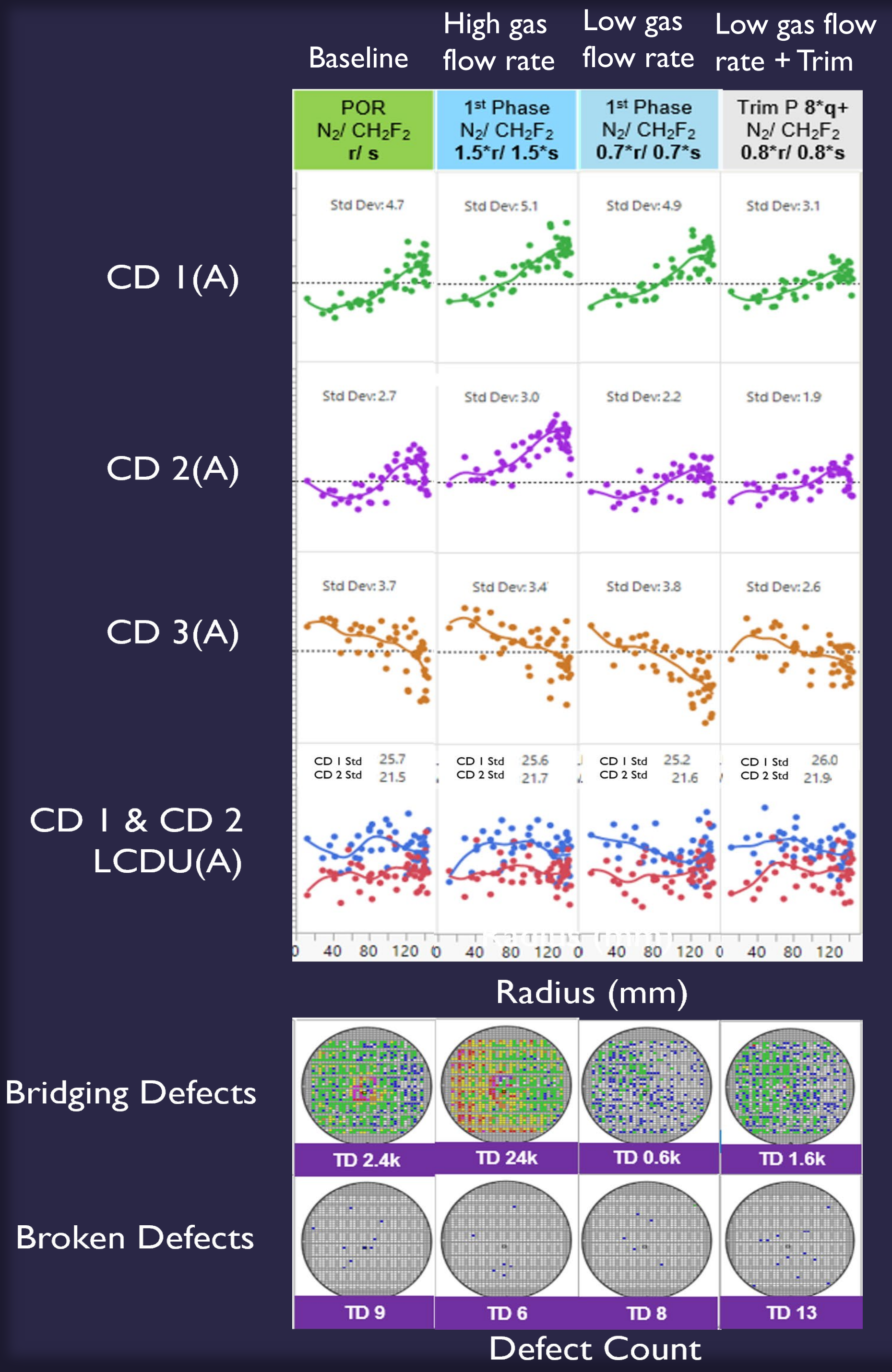
N_2/CH_2F_2 gas flow rate adjustment in descum step helps achieve desired polymer deposition amount and CD uniformity



At higher flow rates, CD 3 edge roll off is lower suggesting polymer has higher impact on etching the chamber wall film compared to fluorine gas chemistry



At lower flow rates, CD 3 standard deviation becomes worse predominantly at the wafer edge. This can be mitigated with trim time adjustment



(r : N_2 sccm, s : CH_2F_2 sccm, q : pressure mT, TD : Total Defect count)

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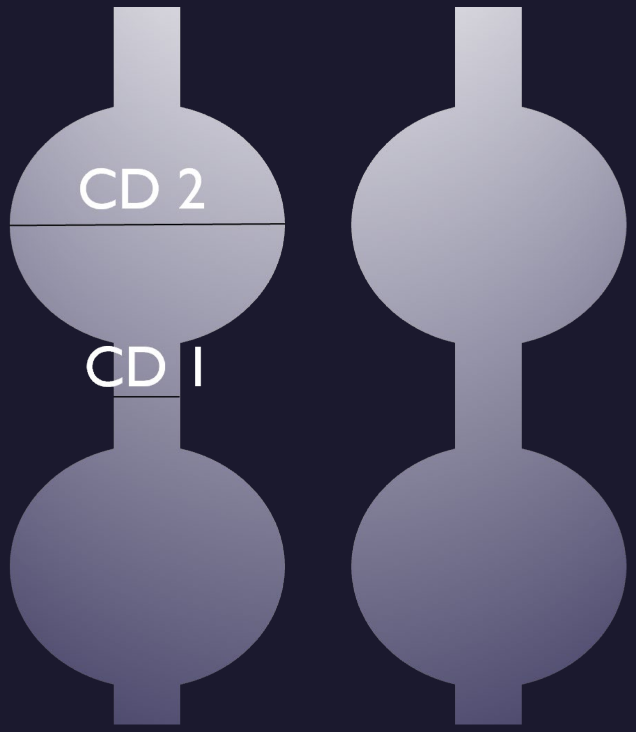
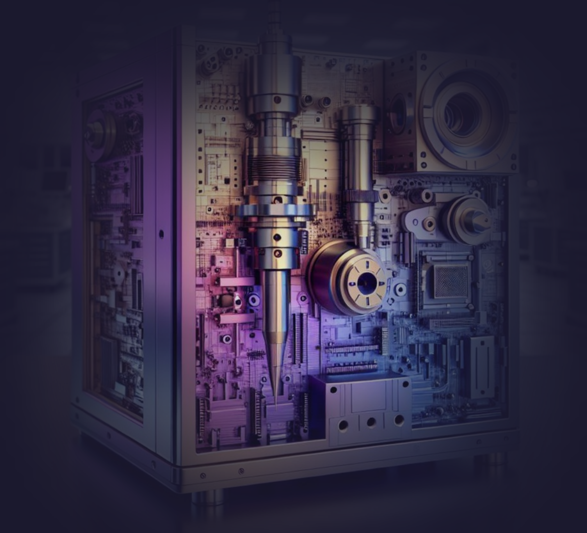
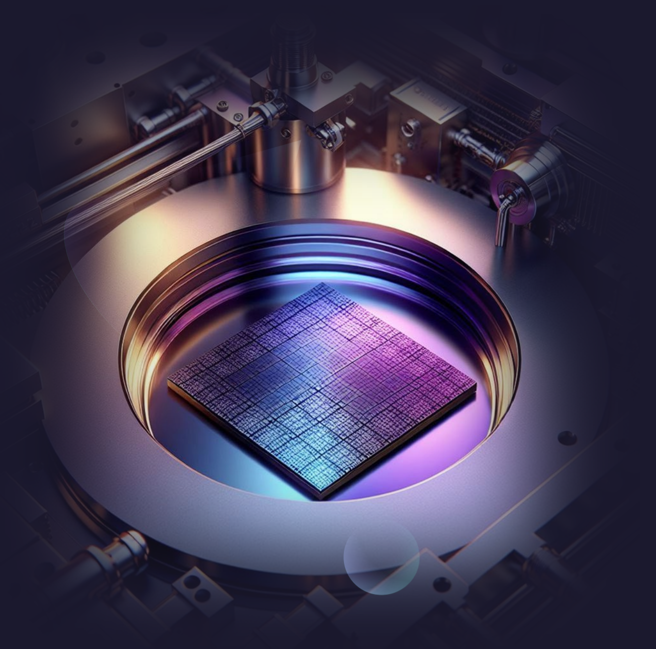
Conclusion

For EUV patterning on complex pattern sub 10 nm solutions were provided to

- Enable large and uniform surface area for patterning
- Enable low Local Critical Dimension Uniformity
- Minimize Defects from EUV lithography and Dry Etch technology







Acknowledgment

We would like to acknowledge the contributions of TEL team in helping resolve EUV resist defectivity issue and thank them for great collaboration. We would also like to thank and acknowledge various Micron teams across Boise and Taiwan including Process Integration, Process Technology, RDA, Metrology, Characterization, and Operations team.

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*Copilot images *copywrite slide deck

Thank you

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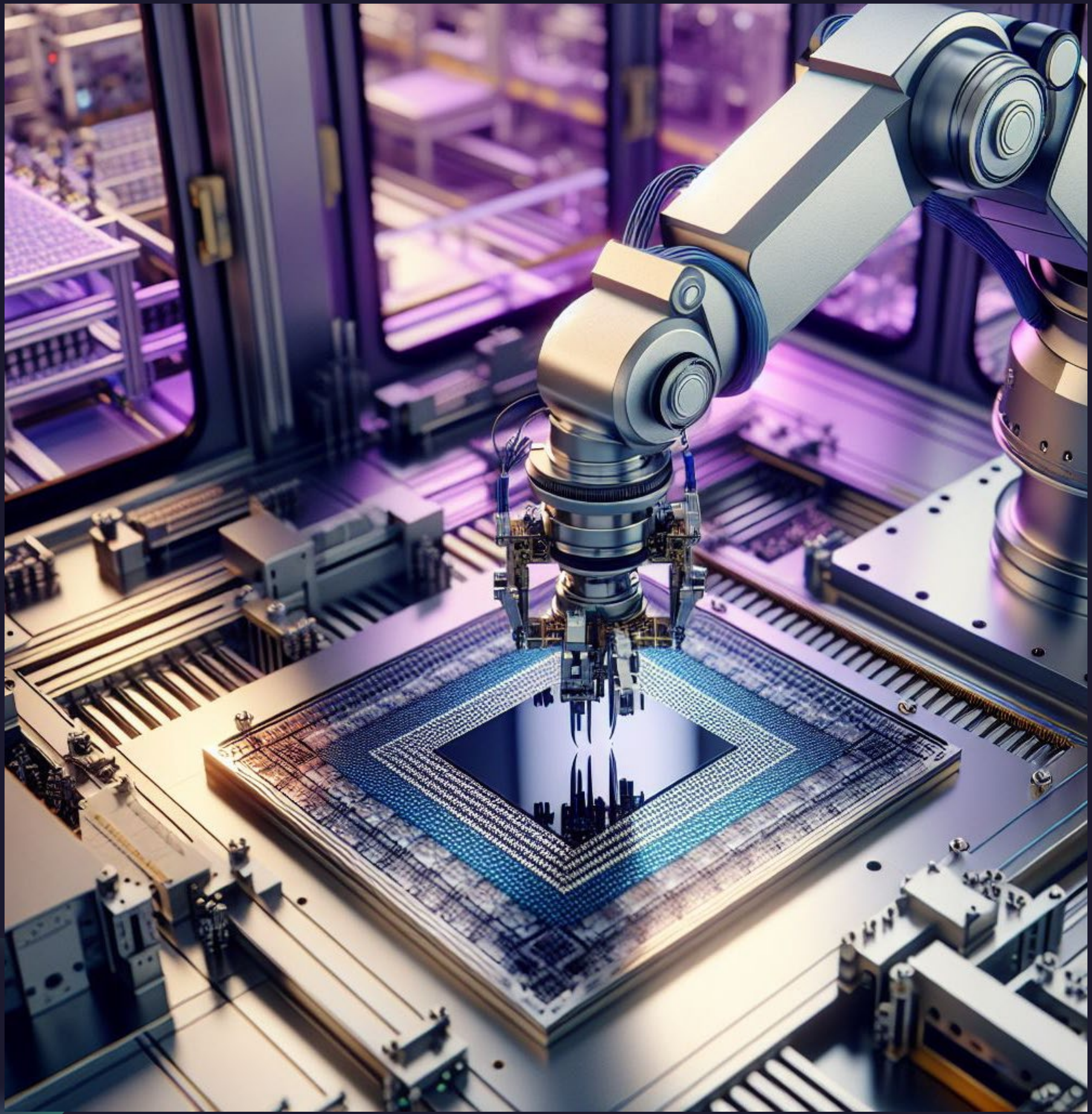

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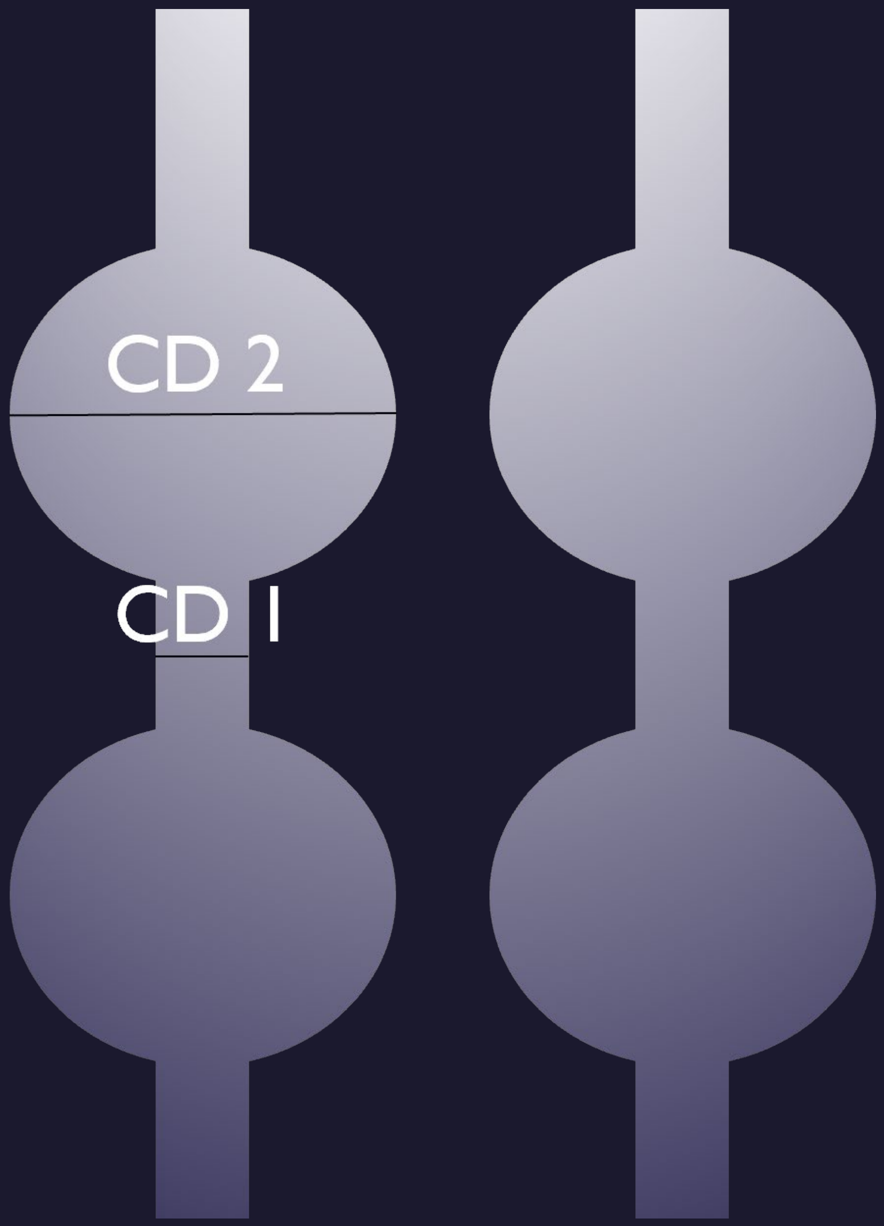
Novel Complex EUV Pattern

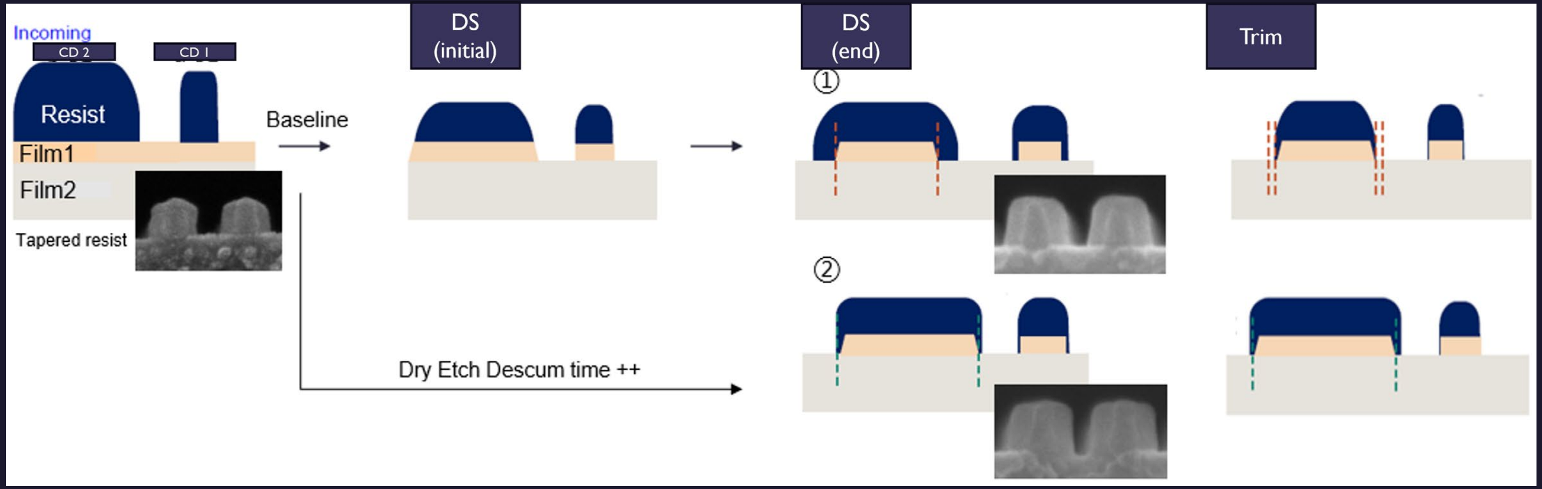
CD 1 = line CD
CD 2 = spherical curvature CD
CD 3 = CD 2 – CD 1



CD= Critical Dimension

Appendix

1st phase Film1 Dry Etch, descum-trim cycle implemented to preserve EUV mask shape



- *Descum: Etch Film1 + Dep on Resist to preserve mask shape*
- *Trim:Trim Resist + Etch Film1, increase trim capability to mitigate micro bridging caused by descum deposition*

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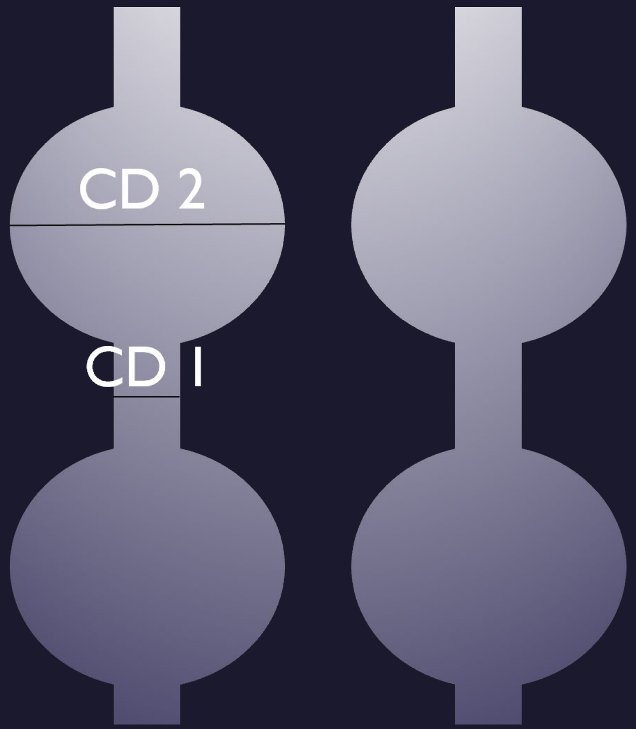
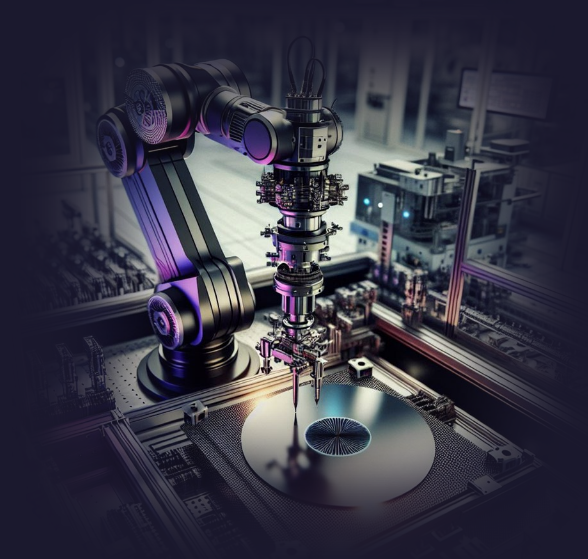
Table Bridging and Broken EDL comparison of DS Gas Skew. ([a]: Baseline)



EDL: Estimated Die Loss

N_2/ CH_2F_2 (sccm)	CD 1& CD 2	EDL % (Bridging)	EDL % (Broken)
1.5*r/ 1.5*s	↑	73.7 (50%↑)	0.12
r/ s[a]	-	24	0
0.8*r/ 0.8*s	↓	0.7 (23%↓)	0
0.5*r/ 0.5*s	↓	0.3 (24%↓)	0



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