Full Reticle Curvilinear Inline Linearity Correction Including Variable Bias with Zero Turnaround Time

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Linearity

Critical Dimension error driven by design size and pitch needs to be corrected.

Mixed Features on Reticle Require Unique Correction

Problem: Without mask process corrections (MPC) feature designs exhibit +30 nm of CD range through pitch and target

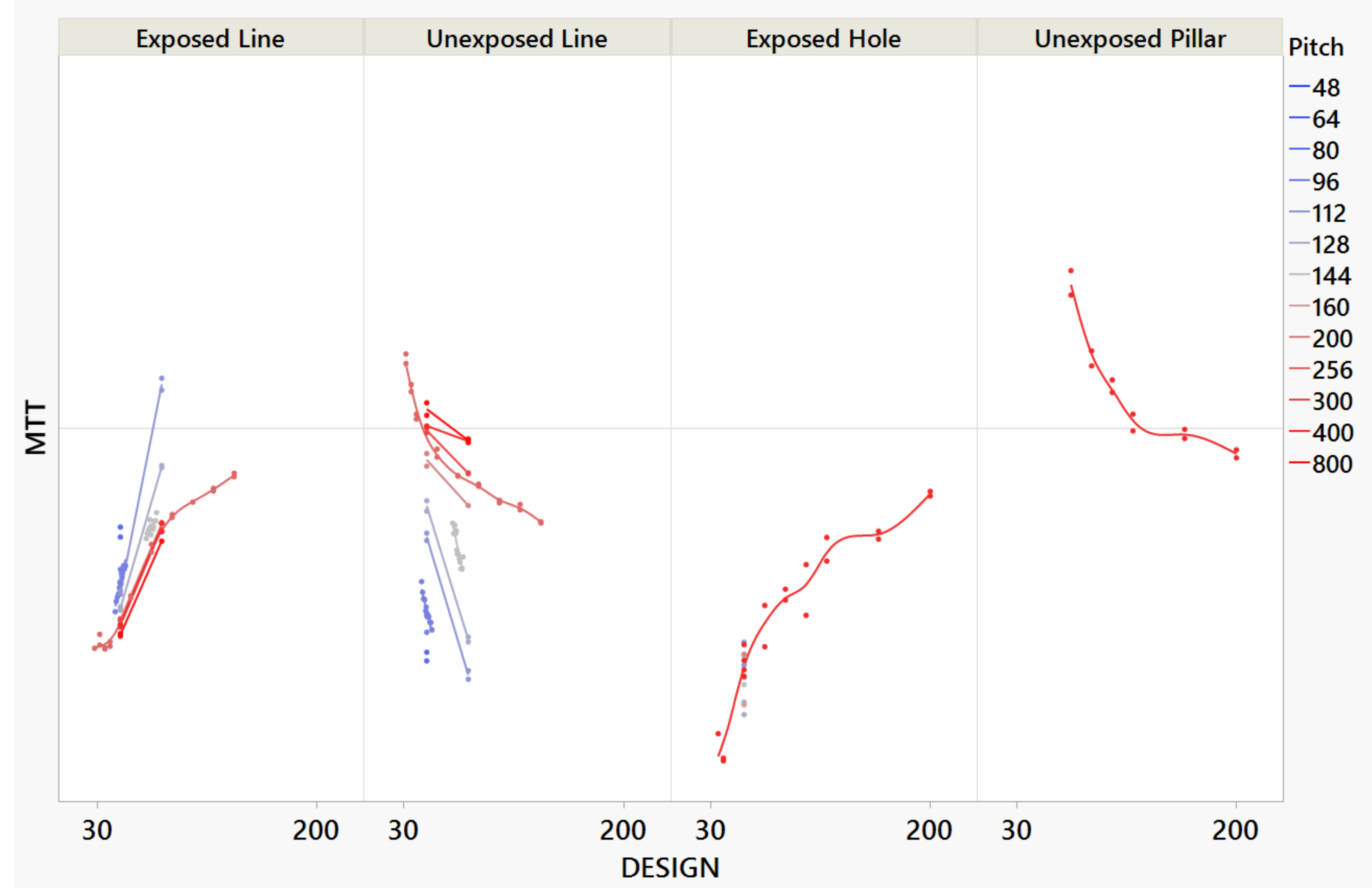
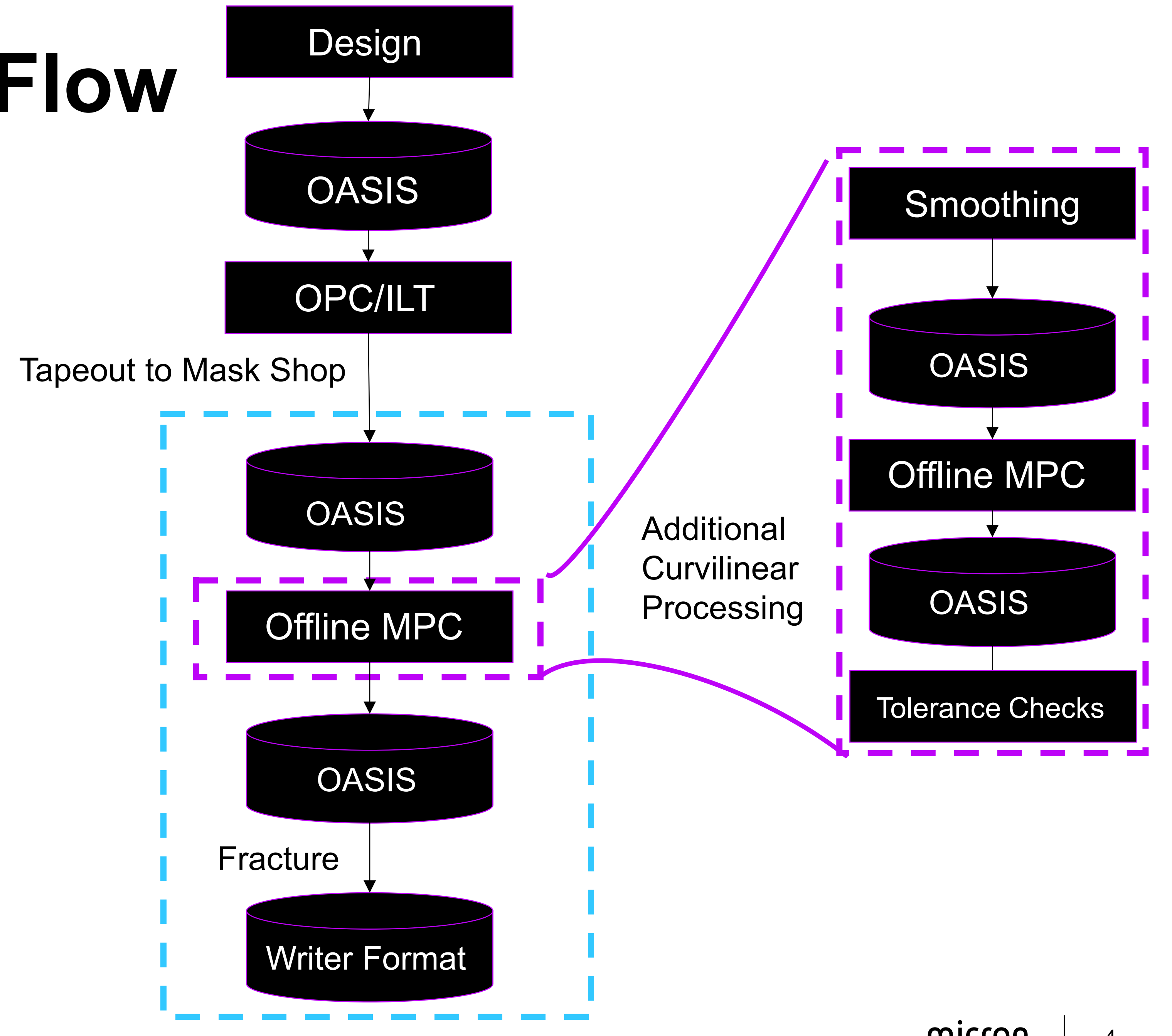


Figure 1: Process error present in an EUV process across features and pitches

Offline MPC Data Flow

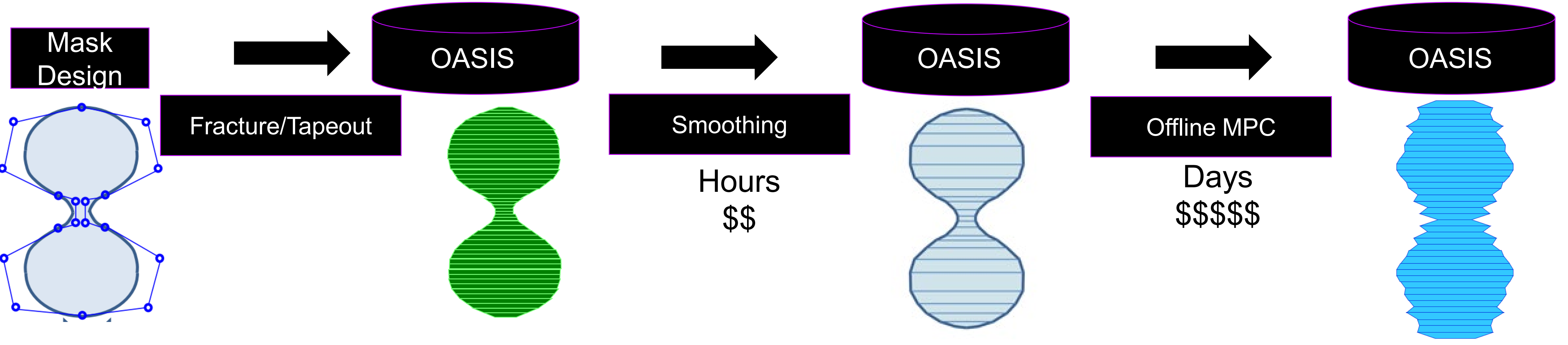
Offline MPC incurs cycle time & monetary cost as part of data flow for:

- Manhattan Data
- Curvilinear Data



Offline MPC Steps for Curvilinear Data

Offline MPC is not just a single step for curvilinear data

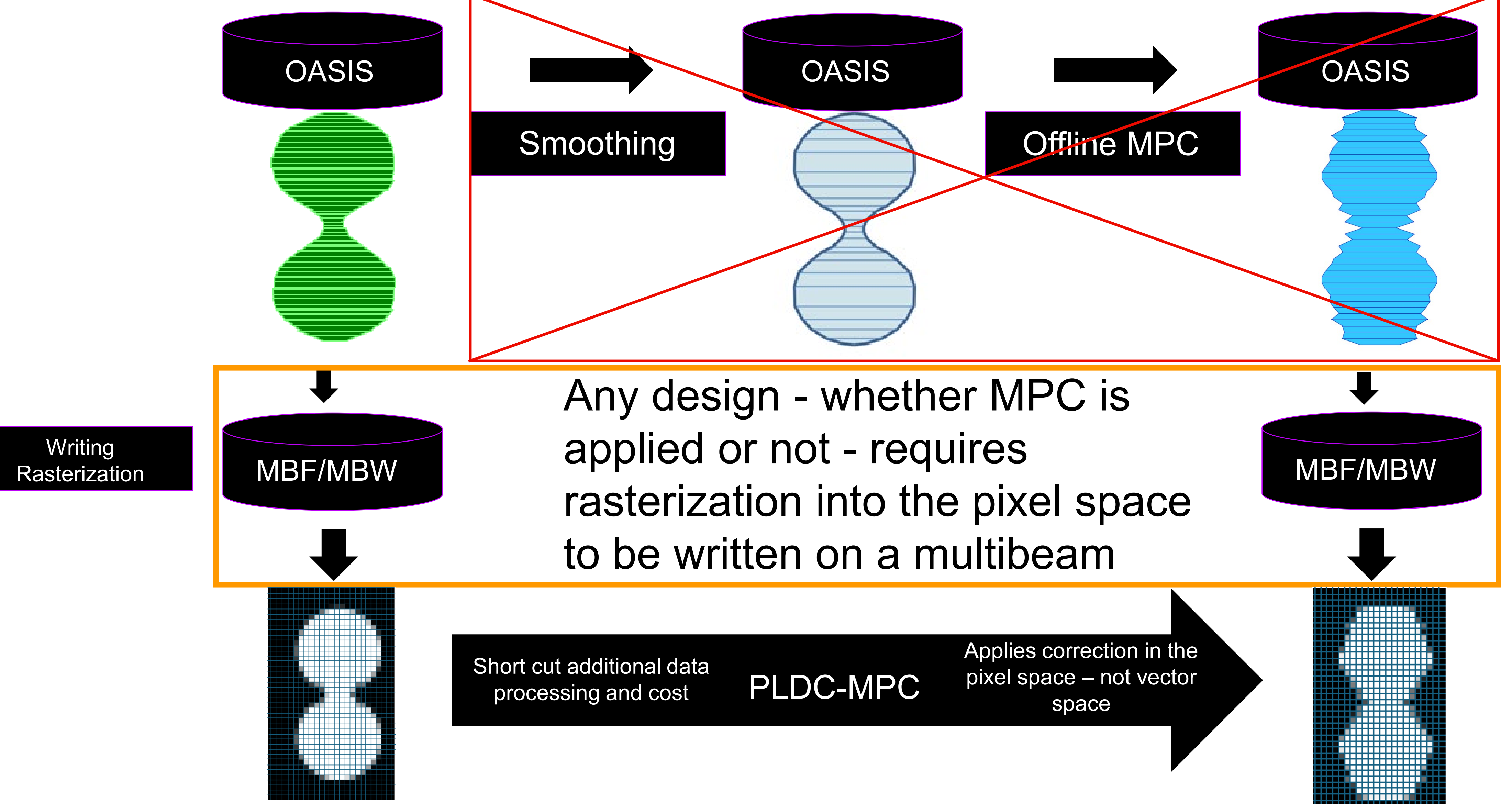


- Offline MPC requires cloud computation to:
  - Prepare the data for offline MPC
  - MPC data processing
- MULTIGON is not a solution to additional computation time.

Can the cost and complexity of offline MPC be eliminated while maintaining CD accuracy?

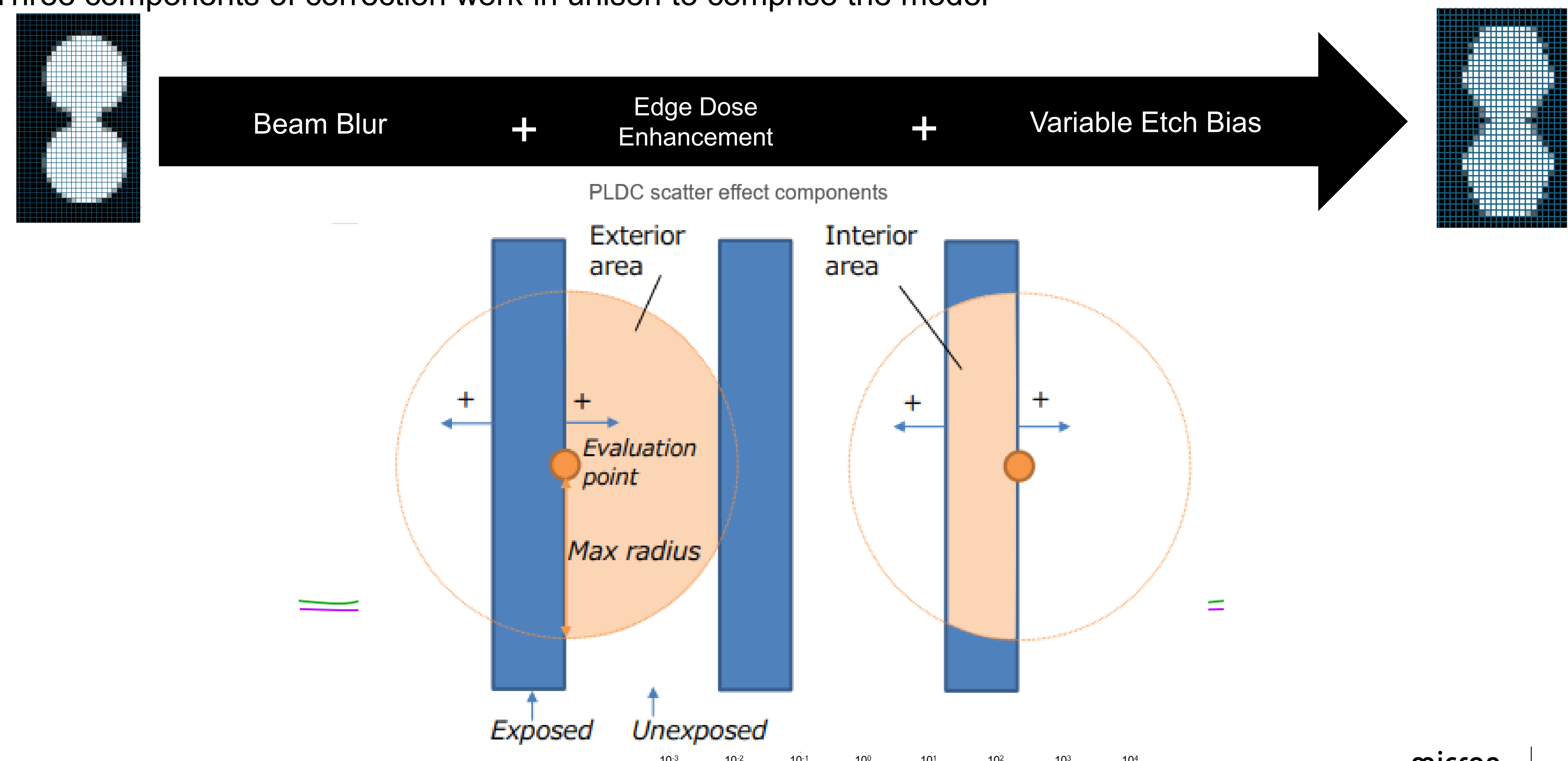
Pixel Level Dose Correction (PLDC) enables a shortcut to MPC’d Designs

Pixel Level Dose Correction (PLDC) Solution



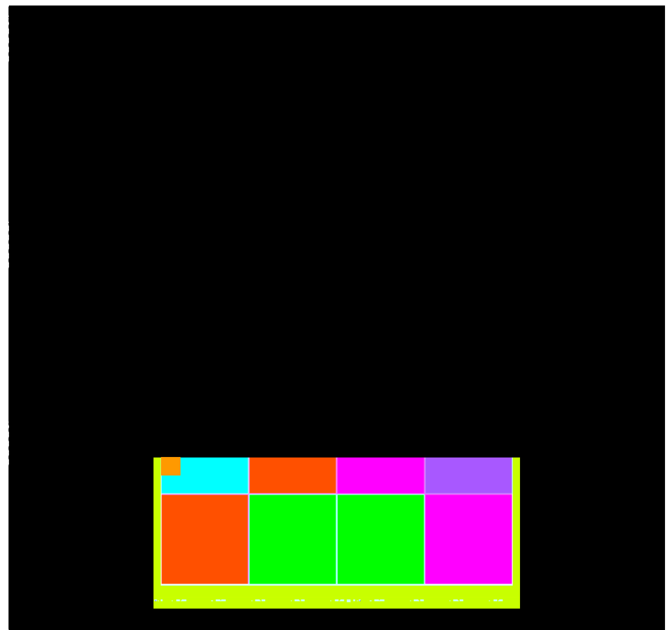
PLDC-MPC Modeling

Three components of correction work in unison to comprise the model



PLDC Application

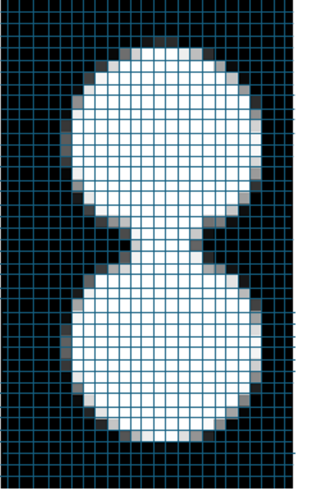
- When: PLDC is applied to the mask during writing
- Where: PLDC is applied to every written field on the mask
- How: As the mask data is rasterized into the pixel space. Calculations from the previously discussed model are applied and modified data is applied to every structure within the field of view.

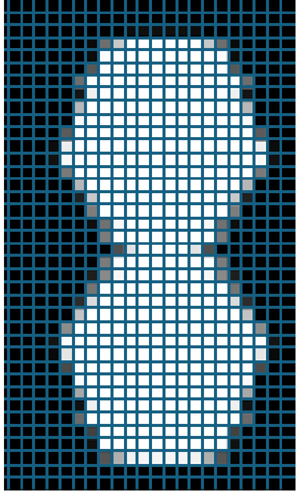


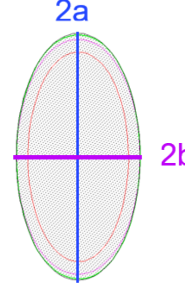
How is PLDC-MPC Verified

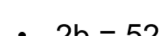
- Traditional MPC can be checked in the data either by visual XOR, or rule based XOR
- PLDC-MPC which happens in line requires a different approach:
  - Pixel maps of individual CD sites can be compared, but not necessarily meaningful to the viewer
  - Emulation software is available to show in vector space the predicted contour placement.
  - Full demonstration at Ebeam Initiative Finale

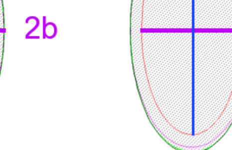
Which Pixel Image is correct?

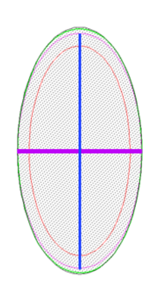


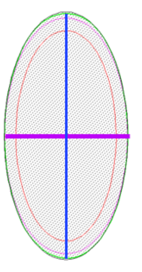












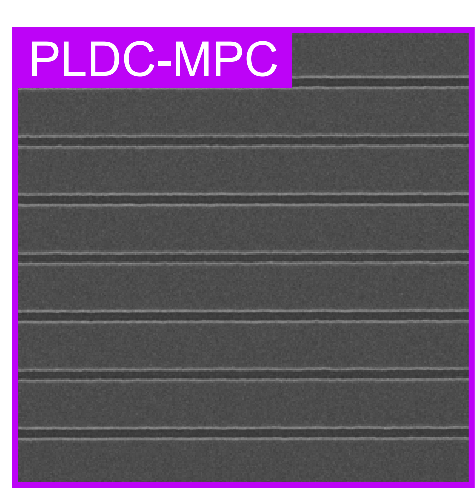
Design	No Correction	Biased Correction	PLDC-MPC
• 2b = 64	• 2b = 52	• 2b = 64	• 2b = 64
• 2a = 128	• 2a = 108	• 2a = 122	• 2a = 126
• E = 0.86	• E = 0.88	• E = 0.85	• E = 0.86

Results: Manhattan Patterns

Inline MPC vs Offline MPC

Clear line (exposed)

- PLDC-MPC exceeds best offline MPC vendor



POR | A | B | C | PLDC

Offline MPC Vendors

Range: Baseline

Range reduction vs baseline: 42%

Range reduction vs baseline: 21%

Range reduction vs baseline: 42%

Range reduction vs baseline: 67%

Pitch
96
112
128
144
200
256
300
400
800

MTT

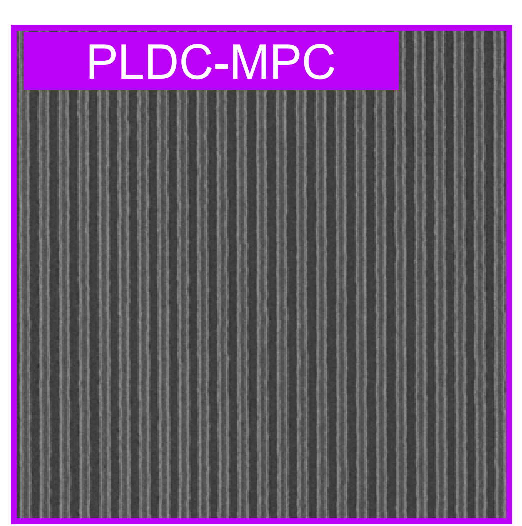
30 200 30 200 30 200 30 200 30 200

DESIGN

Inline MPC vs Offline MPC

Dark line (unexposed)

- PLDC-MPC exceeds best offline model performance



POR | A | B | C | PLDC

Offline MPC Vendors

Range: Baseline

Range reduction vs baseline: 54%

Range reduction vs baseline: 68%

Range reduction vs baseline: 50%

Range reduction vs baseline: 81%

MTT

30 200 30 200 30 200 30 200 30 200

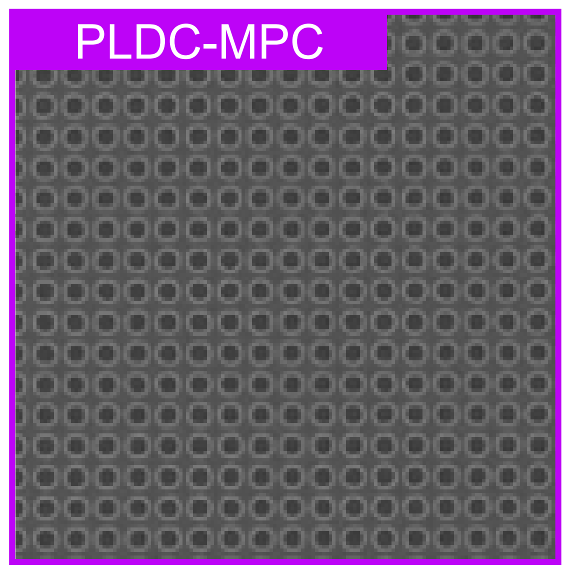
DESIGN

Pitch
80
96
112
128
144
200
256
300
400
800

Inline MPC vs Offline MPC

Hole Space

- PLDC-MPC showed the best performance compared to offline models



POR | A | B | C | PLDC

Offline MPC Vendors

Range: Baseline

Range vs baseline: 44%

Range vs baseline: 57%

Range vs baseline: 56%

Range vs baseline: 67%

Pitch
112
128
144
160
200
400

MTT

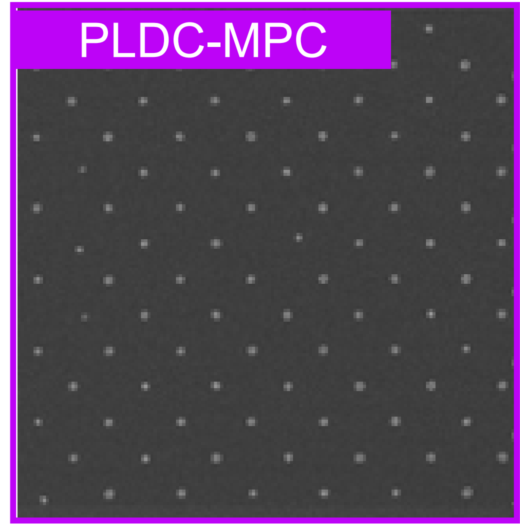
30 200 30 200 30 200 30 200 30 200

DESIGN

Inline MPC vs Offline MPC

Dark Pillar

- Offline MPC performed better than PLDC-MPC
- Best MPC performer was C



POR A B C PLDC

Pitch
400

Offline MPC Vendors

MTT

Range: Baseline

Range reduction vs Baseline: 54%

Range reduction vs Baseline: 62%

Range reduction vs Baseline: 69 %

Range reduction vs Baseline: 38%

30 200 30 200 30 200 30 200 30 200

DESIGN

Results Summary

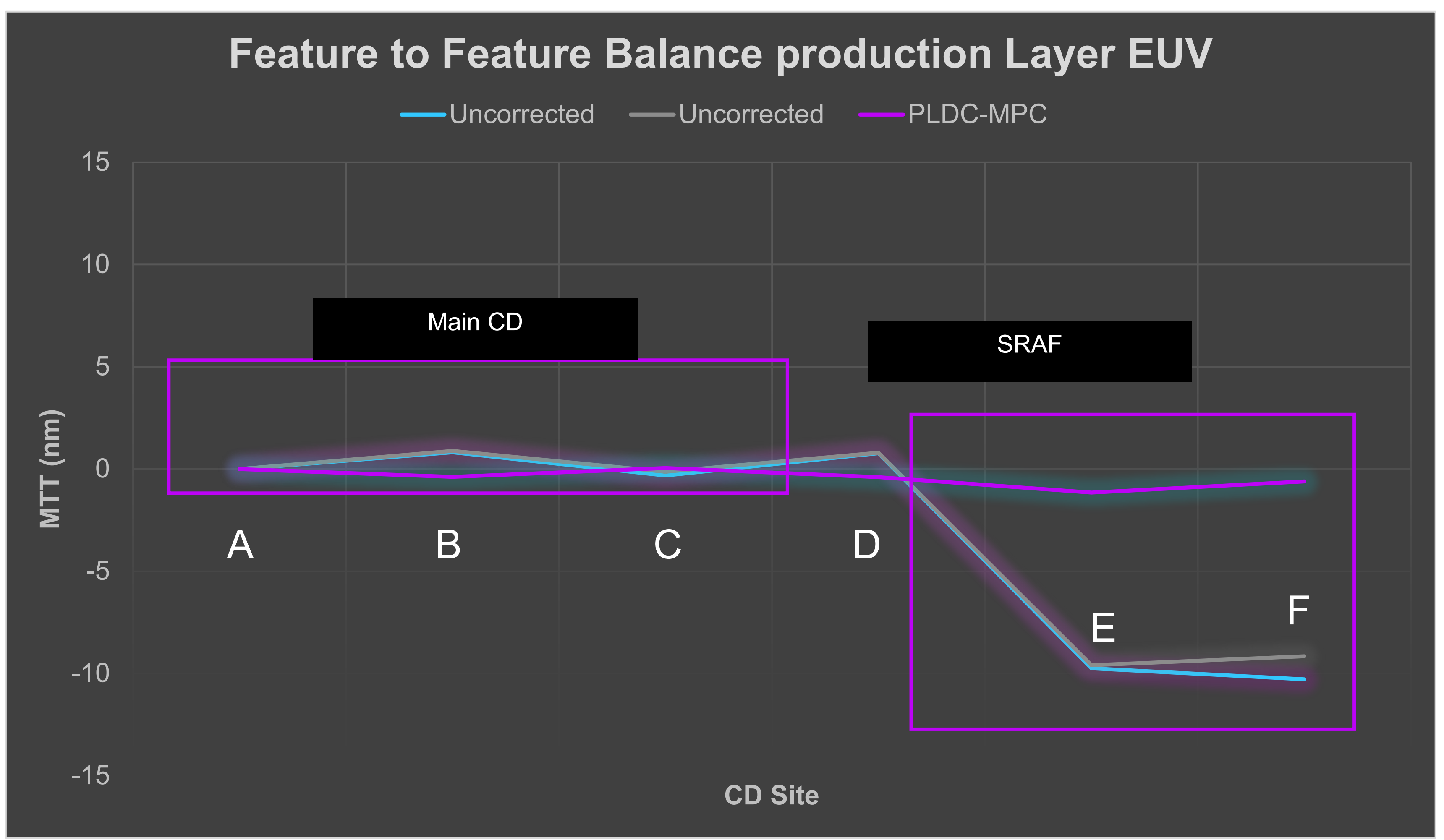
- PLDC-MPC outperforms offline MPC in three categories
- No Offline MPC model lead offline results in more than 2 categories:
  - Dark Line: Vendor B
  - Clear Line: Vendors A/ C
  - Clear Hole: Vendor B
  - Dark Pillar: Vendor C

Results: Production Pattern

Production Layer Feature to Feature Balance

Real Features on Reticle

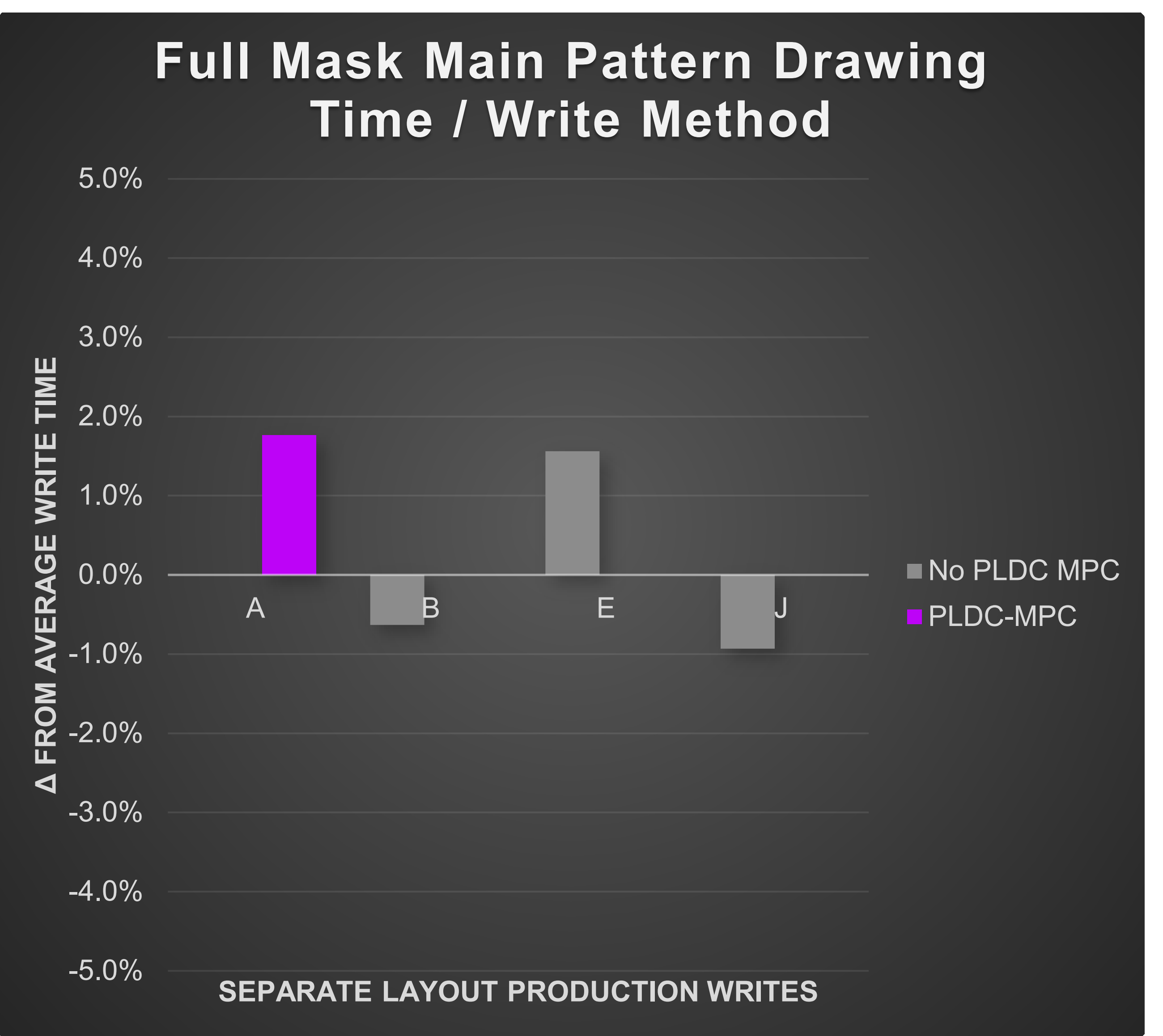
- Eliminates legacy process
  - Done on cloud currently
- Simplifies:
  - Data Processing



Write Time

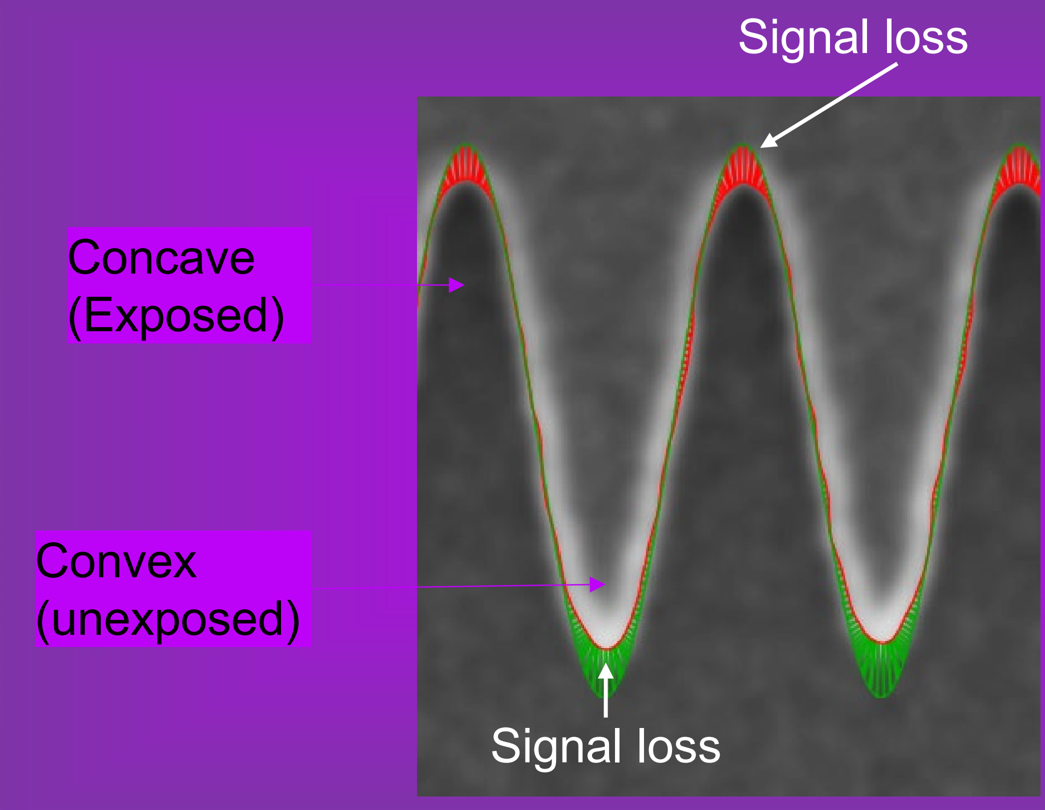
Total write time of PLDC MPC is matched to no MPC

PLDC-MPC correction truly has 0 Turnaround Time during processing



Results: Curvilinear Test Patterns

Curvilinear Edge Placement Error (EPE) Characterization



Convex Curvilinear Characterization

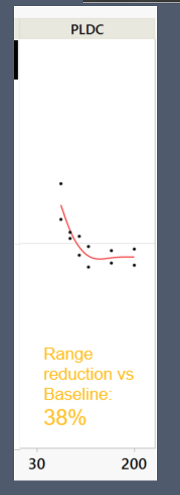
All design amplitudes are 160 nm

PLDC	wavelength design (nm)	Amplitude achieved (nm)	Transfer Ratio	SEM
No	320	149	93%	
Yes	320	147	92%	
No	160	126	79%	
Yes	160	127	81%	

Convex Curvilinear Characterization

All design amplitudes are 160 nm

PLDC	wavelength design (nm)	Amplitude achieved (nm)	Transfer Ratio	SEM
Algo 1	160	127	81%	
Algo 2	160	158	98%	



PLDC-MPC Models are tunable:
Should fix the weakest part of the model for manhattan

Concave Curvilinear Characterization

All design amplitudes are 160 nm

PLDC	wavelength design (nm)	Amplitude achieved (nm)	Transfer Ratio	SEM
No	320	155	97%	
Yes	320	160	100%	
No	160	139	86%	
Yes	160	142	98%	

Concave Curvilinear Characterization

All design amplitudes are 160 nm

PLDC	wavelength design (nm)	Amplitude achieved (nm)	Transfer Ratio	SEM
Algo 1	160	142	98%	
Algo 2	160	139	87%	

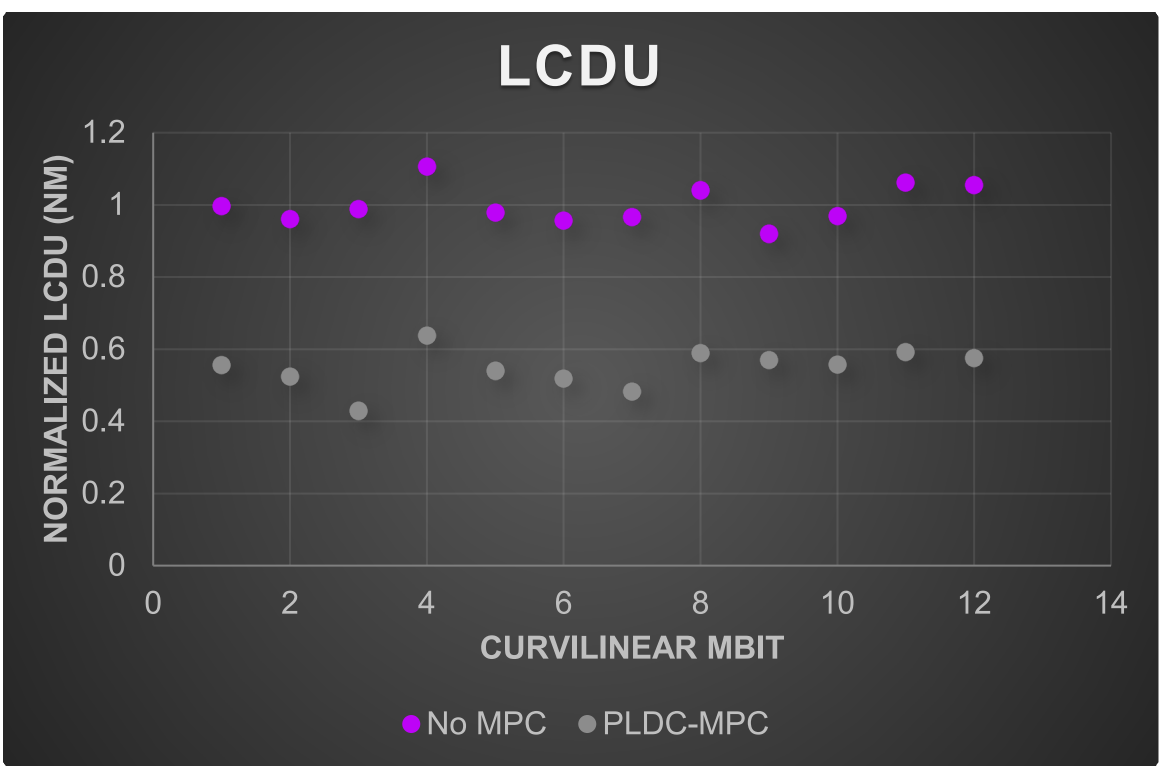
HNA

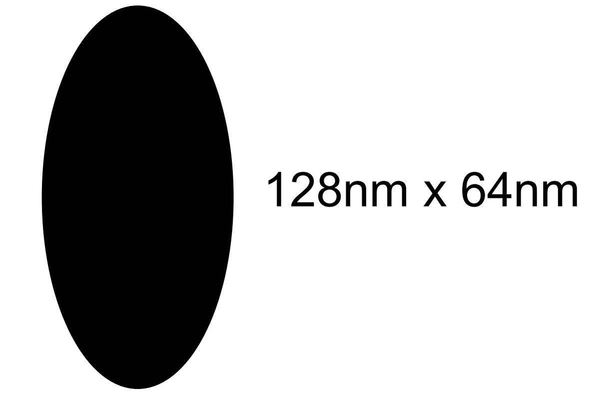
Target on Mask

Target on Wafer

Anamorphic will demand accuracy from curvi designs

- Anamorphic designs will demand tighter pitches resulting in worse LCDU
- If curvilinear designs increase process window – adopting curvilinear will be critical for the anamorphic format of HNA
- Those curvilinear designs will require MPC





16 nm

Conclusion

Conclusion

PLDC-MPC provides a faster, cost effective, solution that meets Micron's requirements to implement MPC.

Micron has begun qualifying PLDC-MPC into production to provide additional value to our customers.

Micron expects to see benefit of PLDC-MPC in HNA pathfinding

This paper a collaboration between:

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