Aki Fujimura, CEO, D2S, Inc. | February 25, 2025

Pixel-Level Dose Correction (PLDC)

Improving Uniformity and Linearity for Manhattan and Curvilinear Masks in 0 TAT

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MPC and PLDC Work for Large Format Masks

- Offline MPC
  - 2x data = 2x TAT impact? No.
    - Two “halves” can have the same OPC/ILT
  - SRAF shifts location across slit in High NA
    - Chips across slit are not repeated in X direction
    - But the two “halves” are in the Y direction
      - OPC/ILT data for a chip can be computed once for both “halves”
      - Offline MPC for local effects are the same
    - Flare correction assumed as per-location bias on mask
  - For 193i, large format doesn’t impact MPC
    - Chips repeat in MPC effects
      - Location dependent mask effects like LEC and FEC are corrected in the machine

- PLDC
  - 0 x 2 = 0
  - PLDC is full reticle processing
    - For all masks, all locations of repeated chips are custom for specific context
      - Includes flare correction either by OPC/ILT or by per-location bias on mask
      - Includes (g)LEC, FEC, and other large-scale density dependent corrections
  - Compute time scales with write time
    - Same computational resource as conventional masks
    - There is more time to compute, because it takes longer to write

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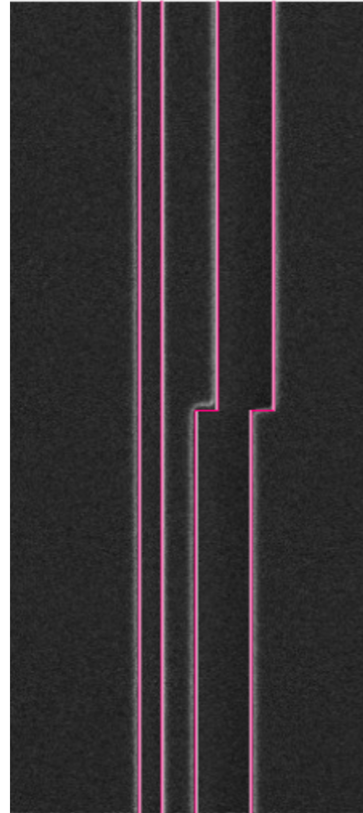
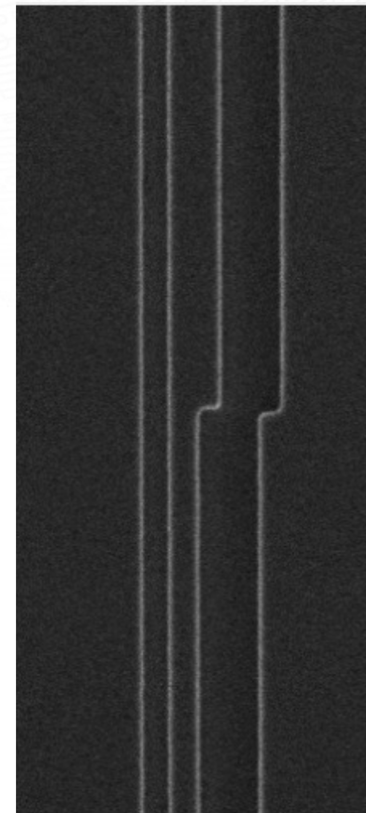
PLDC is Accurate in 0 TAT for Manhattan Shapes

Target

Target and SEM



SEM



SEM : courtesy of NuFlare Technology

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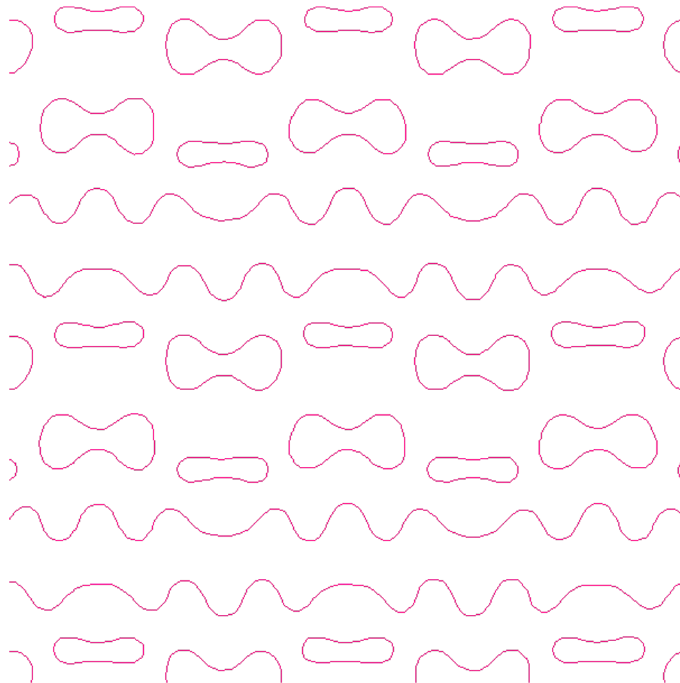
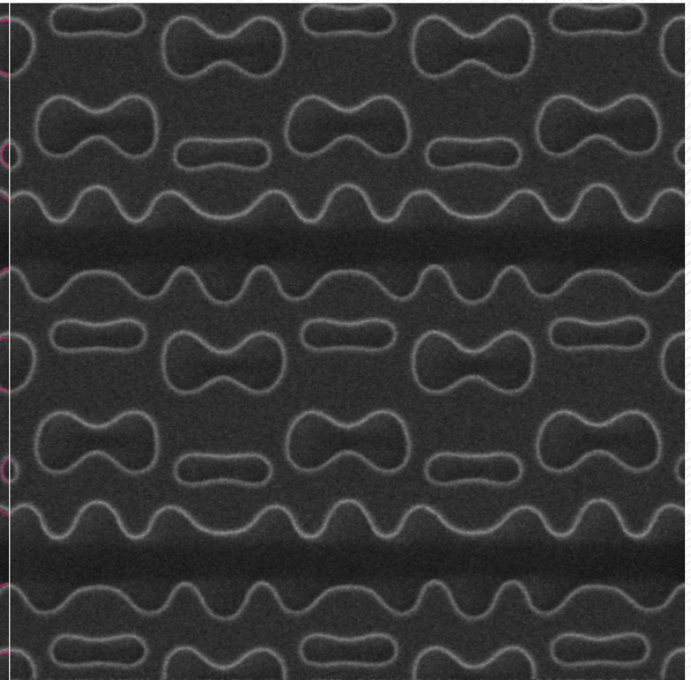
PLDC is Accurate in 0 TAT for Curvilinear Shapes

Target



Target and SEM

SEM



SEM : courtesy of NuFlare Technology

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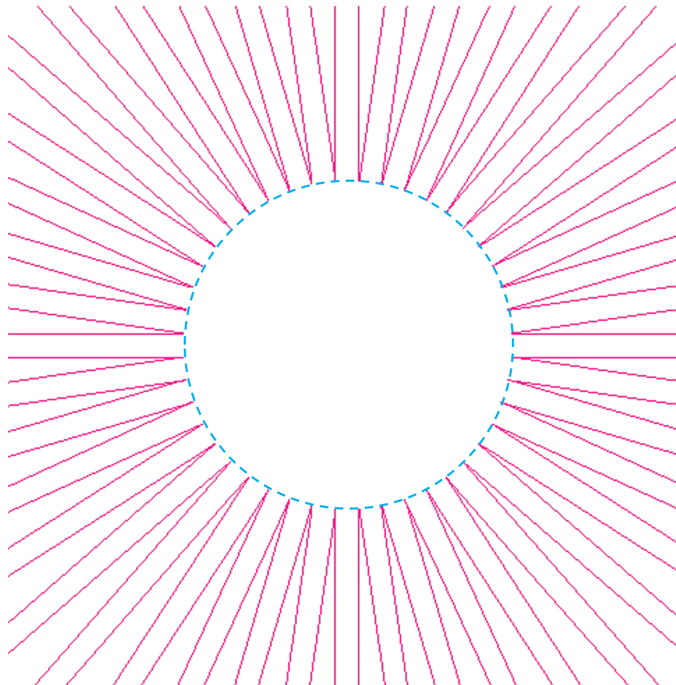
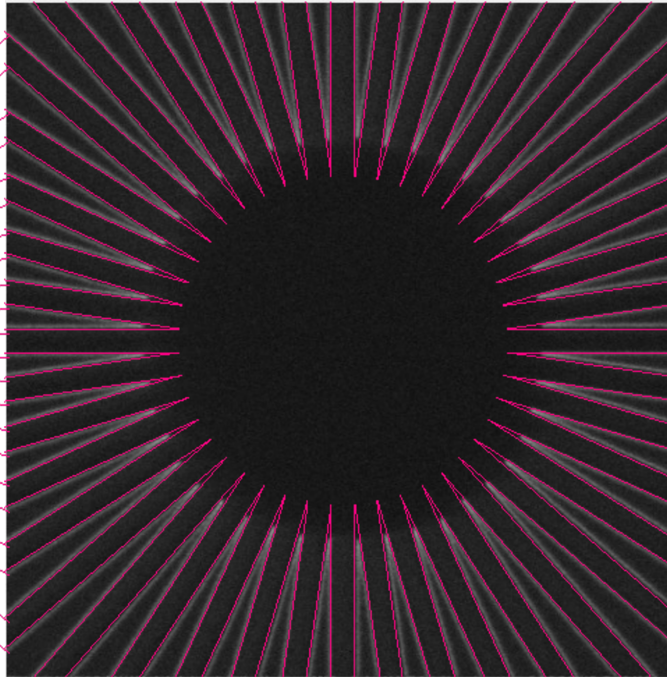
PLDC Works Well For All Angles

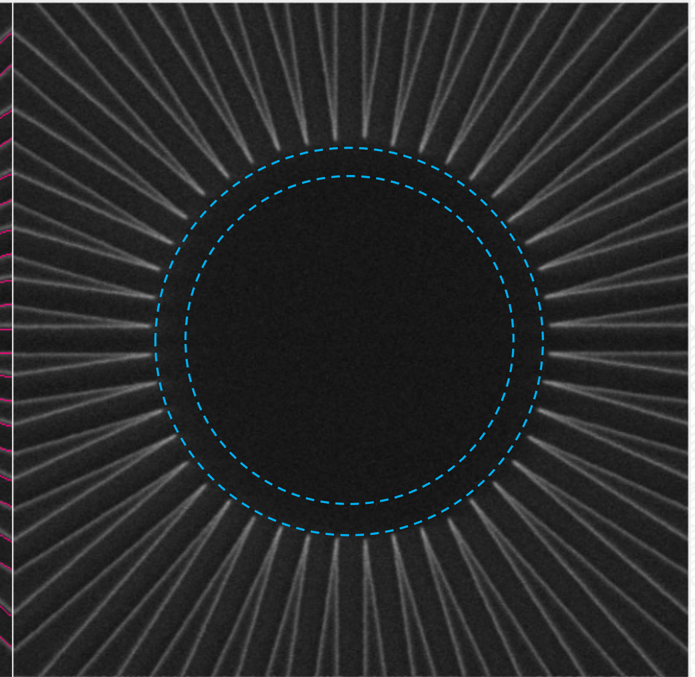
Target



Target and SEM



SEM



SEM : courtesy of NuFlare Technology

Maximum curvature limit of mask process makes the circle bigger, but that it is still a circle is the key to this test

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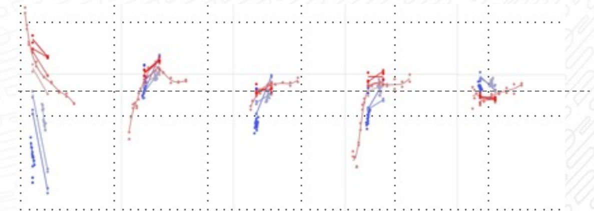
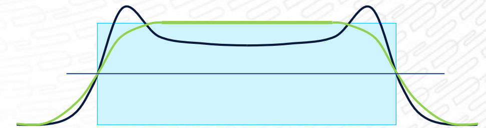
What's Different About PLDC?

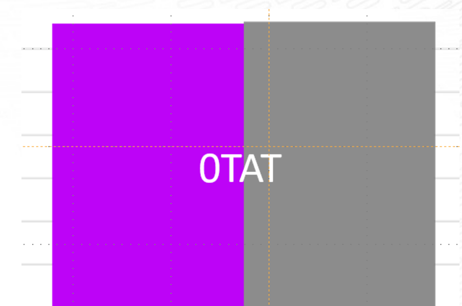
- Improves masks for any mask shape
  - Manhattan, diagonal or curvilinear



- Improves both linearity and uniformity
  - Linearity includes both dose-based and variable bias effects
- Works on any mask, including 193i, EUV, High-N/A…
  - Corrects the full reticle with all chips in local context



- 0 TAT
- Publications from mask shops now available:



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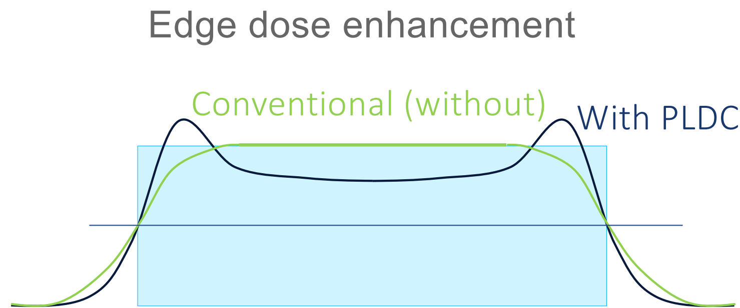
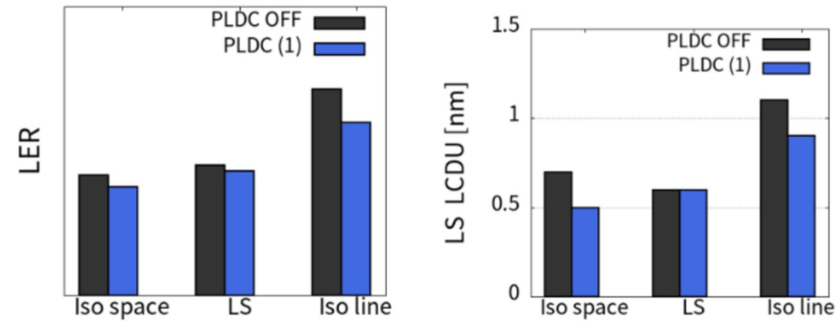
PLDC Edge Dose Enhancement Improves LCDU

For both Manhattan and curvilinear shapes





		Iso space	Line Space	Iso line
LER	Ratio of ON /OFF	0.87	0.96	0.84
LCDU	PLDC OFF	0.7 nm	0.6 nm	1.1 nm
	PLDC (1) ON	0.5 nm	0.6 nm	0.9 nm

PLDC(1) is "Edge dose enhancement“
Note PLDC(1) has better LER and LCDU in all densities

SPIE. PHOTOMASK TECHNOLOGY 2024

Mayuko Matsumoto, Naoki Yoshida, Tetsunori Hirata, Makoto Motegi, Kiyoshi Kageyama, Mitsuharu Yamana, Wataru Kunishima, Ryo Iikubo, "Mask performance improvement by pixel level dose correction," Proc. SPIE 13216, Photomask Technology 2024, 132160H (12 November 2024)

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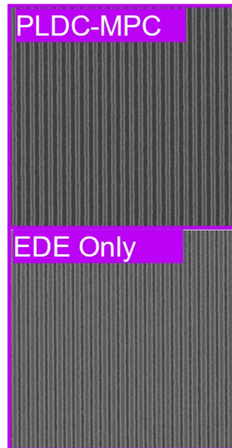
PLDC Linearity Correction has Best Results

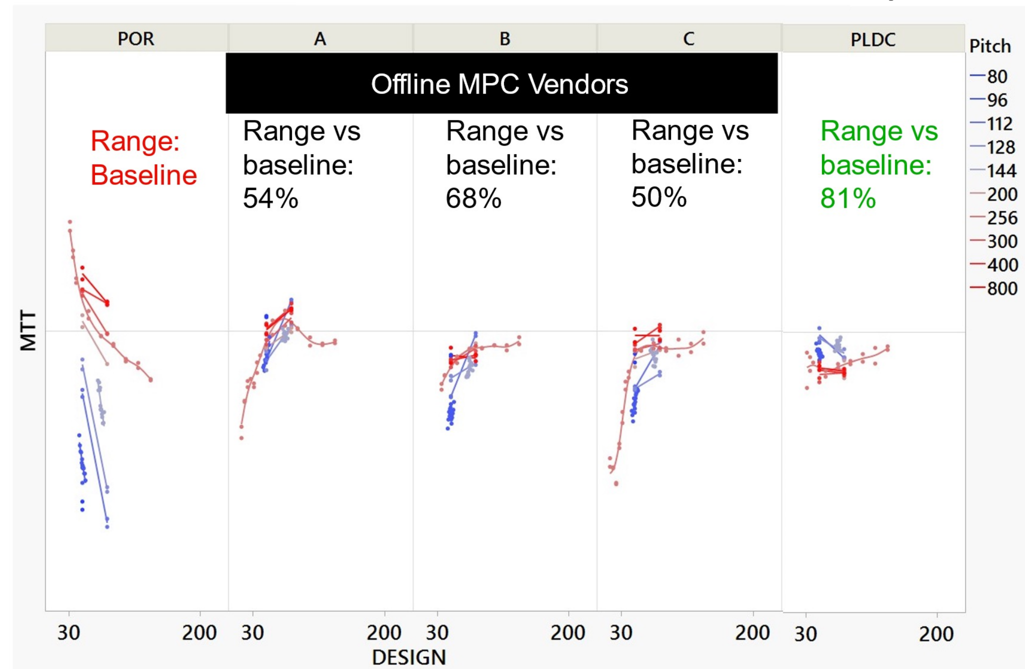
Online MPC vs Offline MPC

Dark line (unexposed)

- PLDC-MPC showed best performance
- Best offline vendor was B



Conventional Manhattan test patterns



SPIE. 2025 ADVANCED LITHOGRAPHY+ PATTERNING

Full-reticle Curvilinear inline linearity correction including variable bias with zero turnaround time, Spinelli, Paris, et al, 2025 SPIE Advanced Lithography + Patterning Symposium, San Jose, CA

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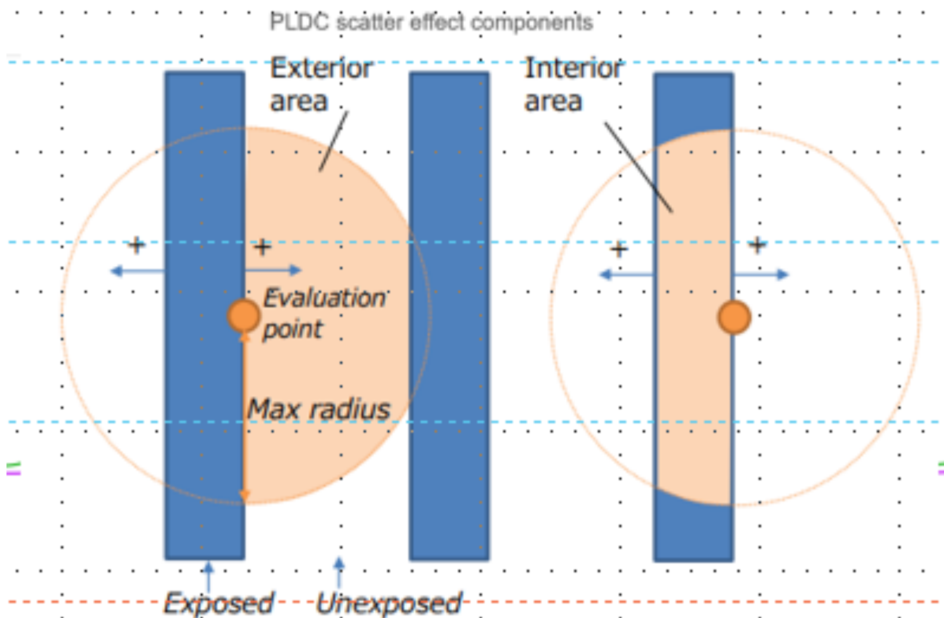
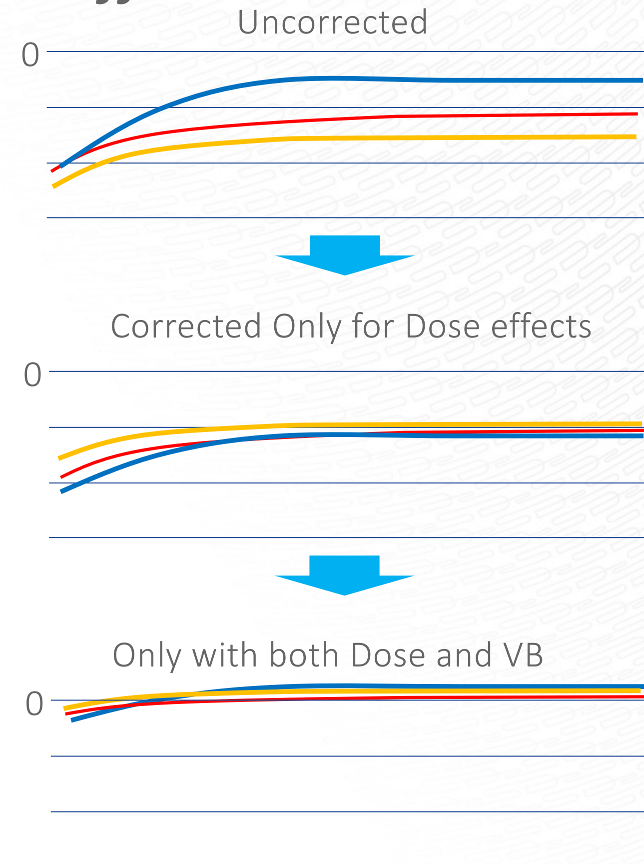
PLDC Corrects Linearity Errors

Both dose-based and variable etch bias effects are corrected

Variable etch bias is an interior effect, but PEC supports exterior calculations for other effects





Plots are conceptual for illustration only

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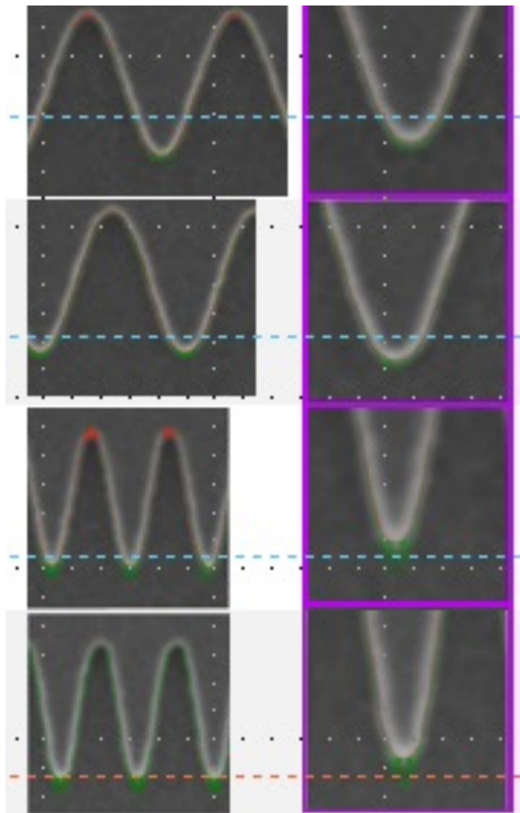
PLDC Works Just as Well for Curvilinear Patterns



- In 0 TAT
- No pre-processing of data
  - No extra processing time
  - No extra files and no expansion of file sizes
- Both dose-based and variable bias
- Edge enhancement of curvilinear edges
  - Uniformity improvement for curvilinear shapes

SPIE. 2025 ADVANCED LITHOGRAPHY+ PATTERNING

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Full-reticle Curvilinear inline linearity correction including variable bias with zero turnaround time, Spinelli, Paris, et al, 2025 SPIE Advanced Lithography + Patterning Symposium, San Jose, CA

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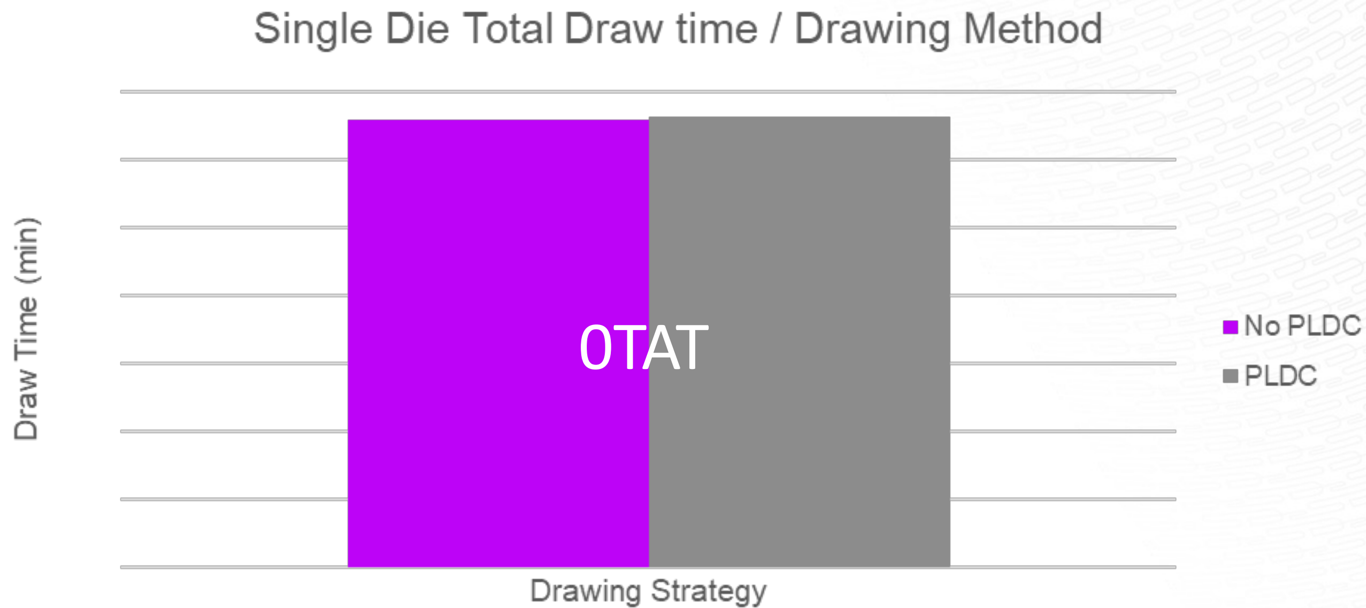
PLDC Delivers with 0 TAT Impact, Including Prep



micron™

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Source: Micron

"Let's not have the mask shop limit wafer production"

- Frank Abboud, IMO

- What would be good for wafer quality that the mask shop couldn't support before in the VSB era?
  - A key theme at BACUS 2025
- PLDC plays a role in this too
  - By enabling full-reticle inline MPC with 0 TAT of curvilinear patterns
  - Makes targeting manufacturable shapes practical, improve CDU on mask and wafer
- Let's remember too that all this enables this:

Paper 13425-40

Integration of curvilinear design into semiconductor logic technology and its manufacturability (Invited Paper)

27 February 2025 • 10:50 AM - 11:10 AM PST | Convention Center, Grand Ballroom 220C

Kim, Ryoung-Han, et al, imec (Belgium)

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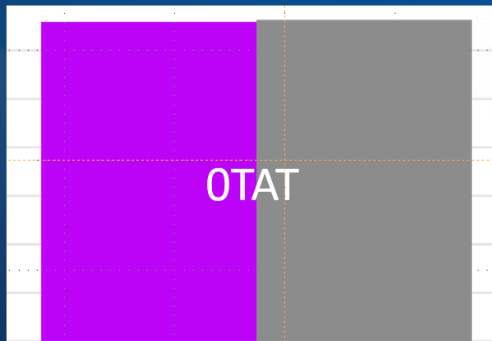
The eBeam Initiative's Finale After PMJ

Join us right after the PMJ 2025 program and in the very same room



Source: Micron

Special Guest: Paris Spinelli, Micron Technology

Learn more about…..

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

5:00pm	Select Japanese whiskey and sake for tasting
5:10pm	In-depth discussion and Q&A with Paris Spinelli
7:00pm	Event concludes with a musical surprise!

April 18, 2025, 4:45 pm, Annex Hall Pacifico Yokohama