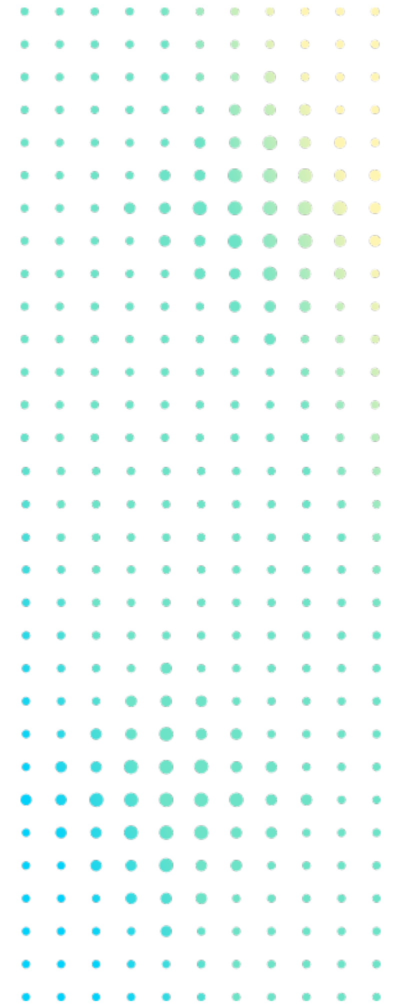
Patterning of Sub-20nm Tip-To-Tip Spacing with 0.33NA EUV Single Exposure of Pitch ≤30nm Line/Space Features Using Dry Resist



Nader Shamma[1], Chris Mack[2], Qinghuang Lin[1], Bill Usry[2], Da Li[1], Benjamin Kam[1], Arame Thiam[3], and Mircea Dusa[3]

[1] Lam Research Corp, Fremont, CA, USA

[2] Fractilia, Austin, TX, USA

[3] imec, Leuven, Belgium

FRACTILIA
COMPUTATIONAL METROLOGY

imec

Overview

01 Background and Motivation
- Impact of tip-to-tip (T2T) CD control on die size
- T2T metrology challenges
- Dry deposited photoresist for EUV lithography

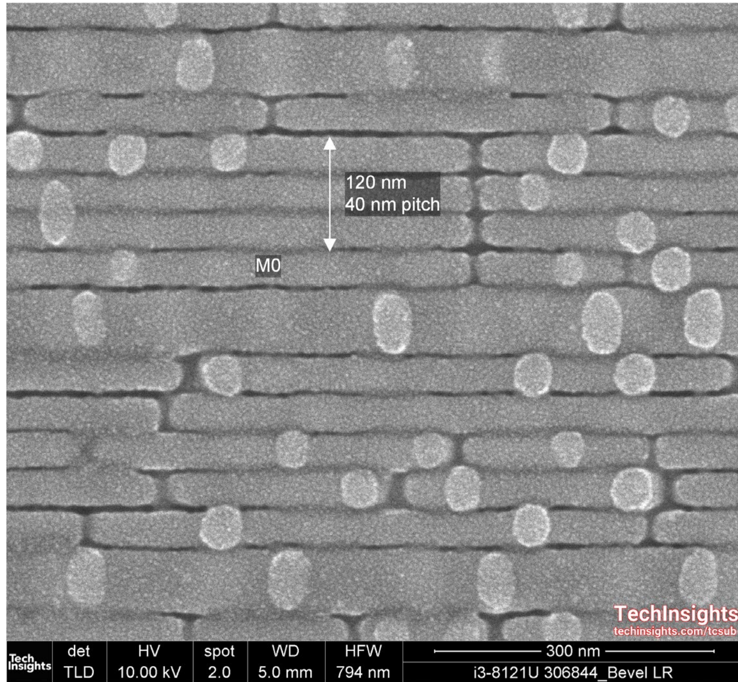
02 Experimental / Results
- EUV Mask design and exposure conditions
- Probabilistic process window
- T2T local CDU results and metrology improvements

03 Conclusions

Why is tip-to-tip CD control important?

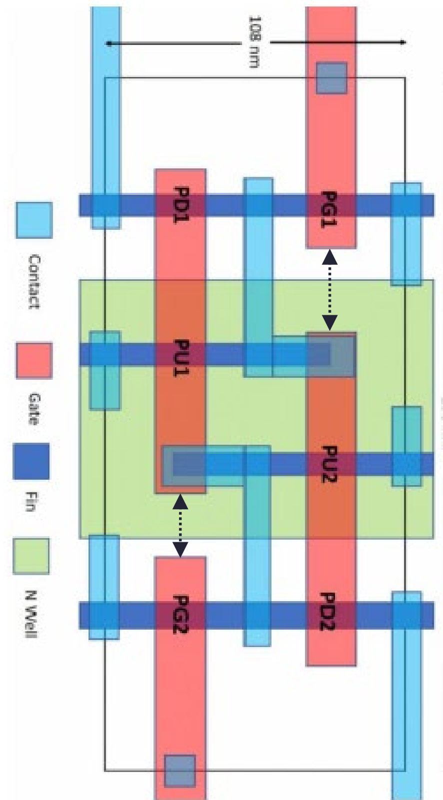
Tighter T2T design rules enabled by lower variability (aka LCDU) → Die area reduction

Intel Tiger Lake 10nm M0 Pitch 40nm

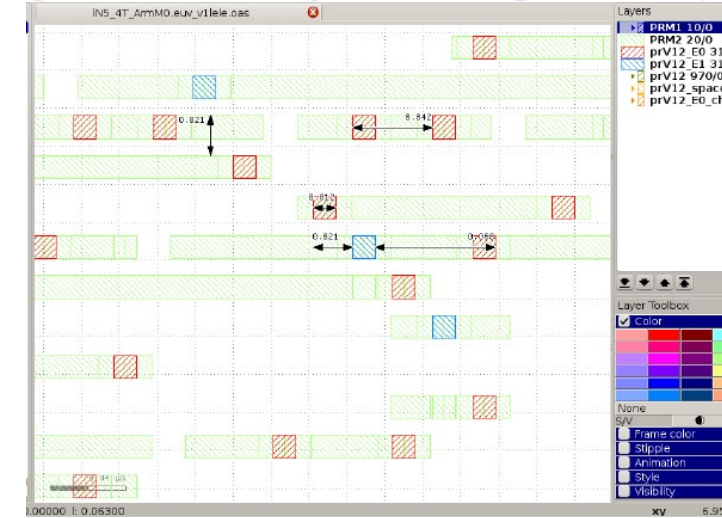


Source: TechInsights

SRAM Layout



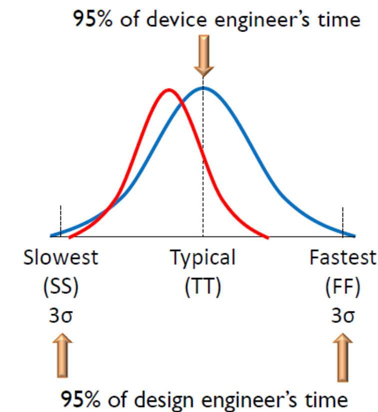
Logic M2-V1 Layout Design Example



Another important scaling law:

Variation $\propto \frac{A_{VT}}{\sqrt{W \cdot L}}$

95% of device engineer's time



95% of design engineer's time

M. Pelgrom

Red process faster than blue process!!

Investing in reducing variability may be more helpful than mobility

IEDM 2015

© 2015 ARM Greg Yeric, ARM

Source: Greg Yeric /ARM

LAM RESEARCH FRACTILIA COMPUTATIONAL METROLOGY imec

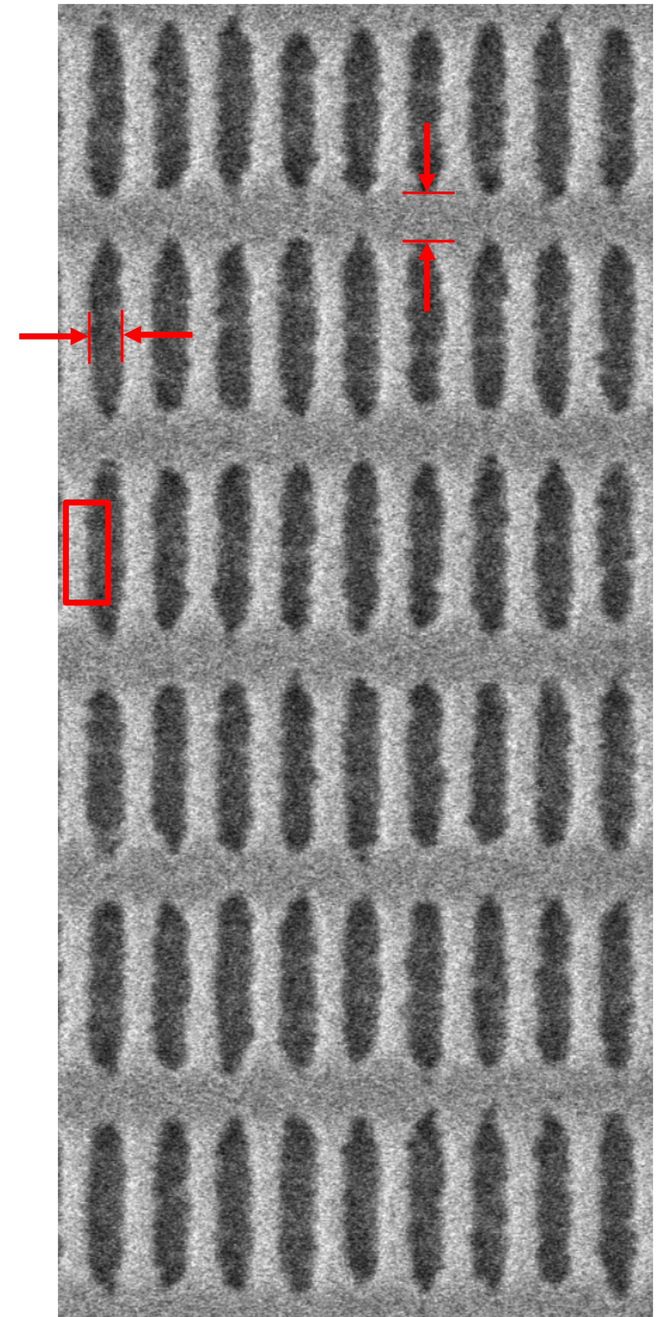
T2T Metrology Challenges

T2T metrology is challenging due to several factors:

- Scan direction effect
- Detection of curved edges
- Feature tip roughness due to EUV stochastics
- Measurements at off-dose and off-focus conditions + FEM analysis
- Need to measure tip-to-tip CD and LCDU, segment CD and LCDU, segment roughness, merged tips, bridged segment spaces

Fractilia approach (MetroLER v3.0.0):

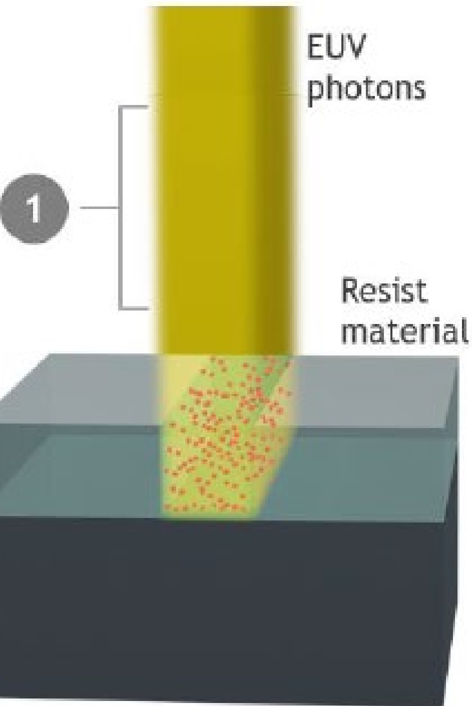
- Inverse Linescan Model (FILM™) for edge detection
- No image filtering or other image processing
- Measure all relevant metrics simultaneously
- Perform Probabilistic Process Window analysis using all relevant metrics



LAM RESEARCH FRACTILIA COMPUTATIONAL METROLOGY imec

Dry Deposited and Dry Developed EUV Photoresist

Fundamentally new resist technology for high-resolution, high-fidelity and low-defect EUV patterning



	Chemically Amplified Resist	Lam EUV Dry Resist
Photoresist Coating	CAR	Small metal-organic units
Photoresist Development	Wet Development Line/Space Solvent 26nm pitch line/space Pillars/Holes/Plugs/Cuts 40nm pitch pillars Pattern Collapse	Dry Development Line/Space 26nm pitch line/space Pillars/Holes/Plugs/Cuts 40nm pitch pillars No Pattern Collapse
Material Usage		5-10x reduction in material waste and cost

CD: 12.0nm
Dose:54mJ

P24 L/S

CD: 17.05nm
Dose: 66mJ

P34 Pillar

CD: 18.9nm
Dose: 54mJ

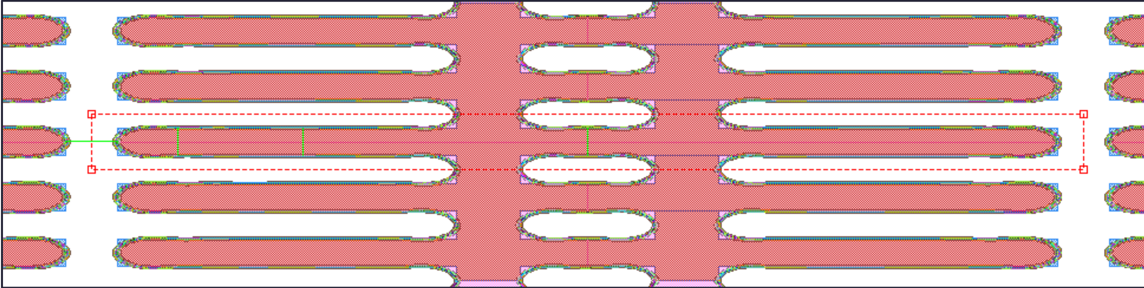
P36 Contact Hole

Lam dry resist technology to enhance performance capability for EUV single expose patterning

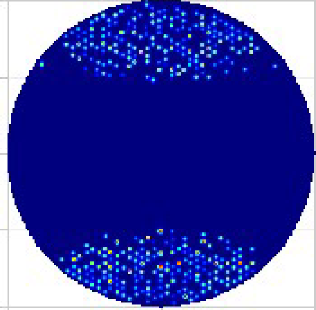
Source mask optimization – verification results

Process variation band (PVB) assessment for dose ±10%, focus ±40nm, mask error ±1nm, flare ±1%

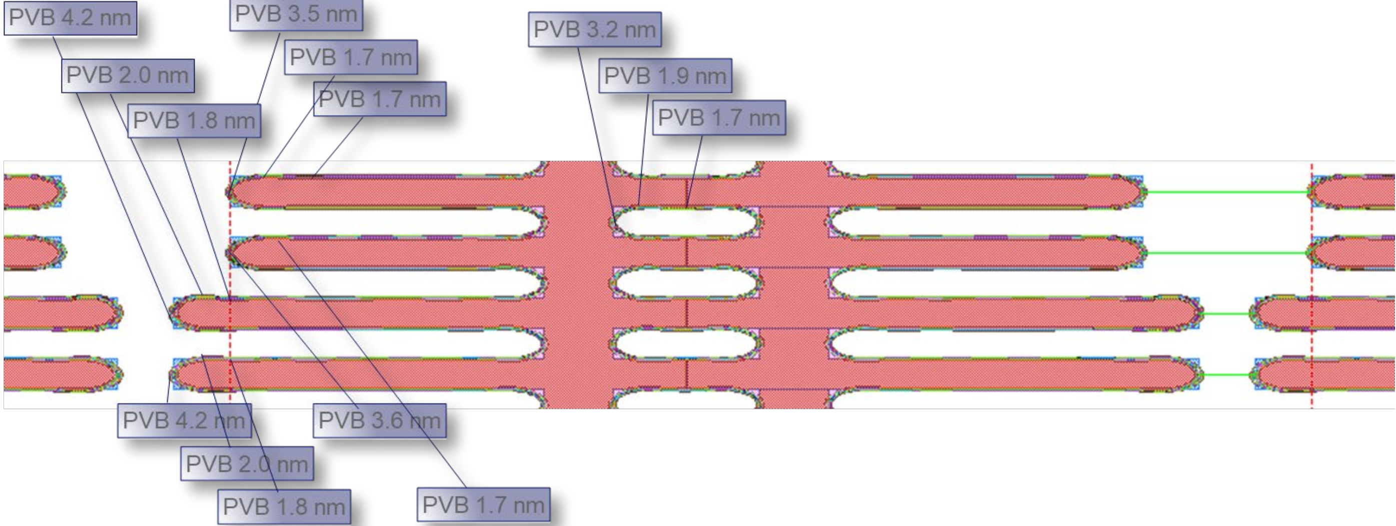
Layout design clip used for source optimization



Optimized pupil

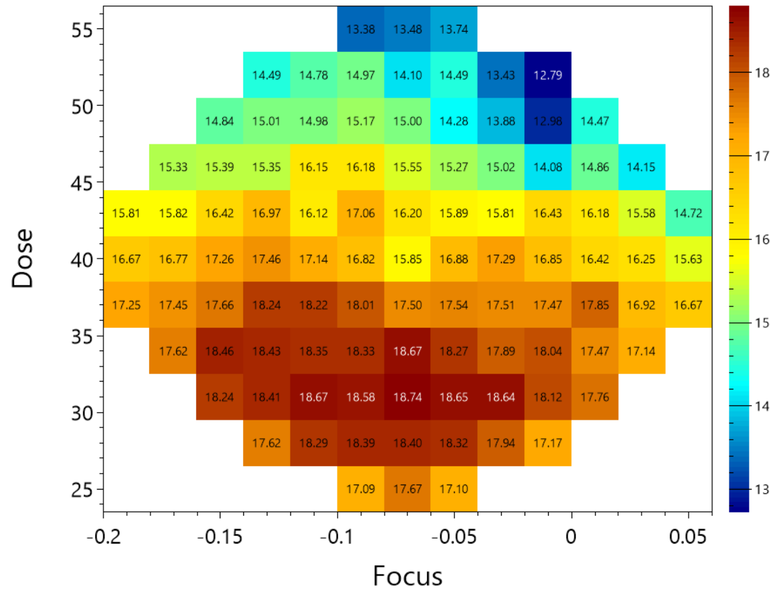


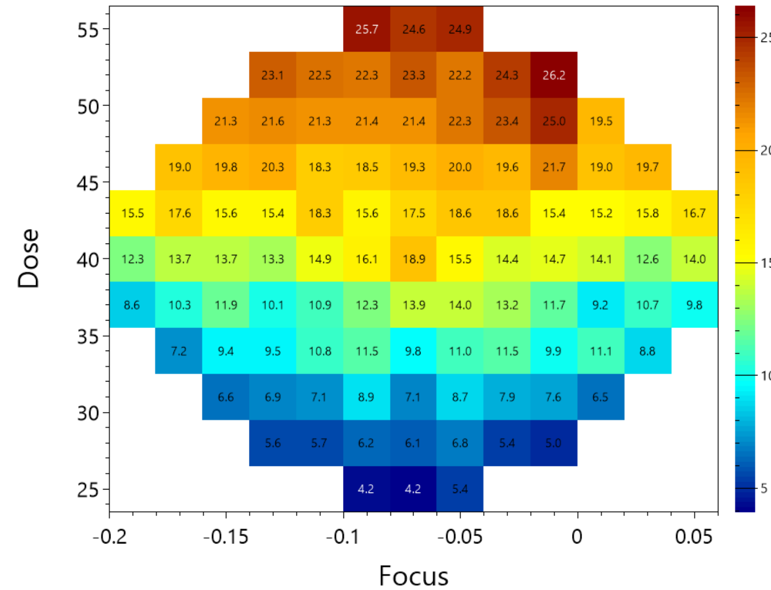
Verification clip

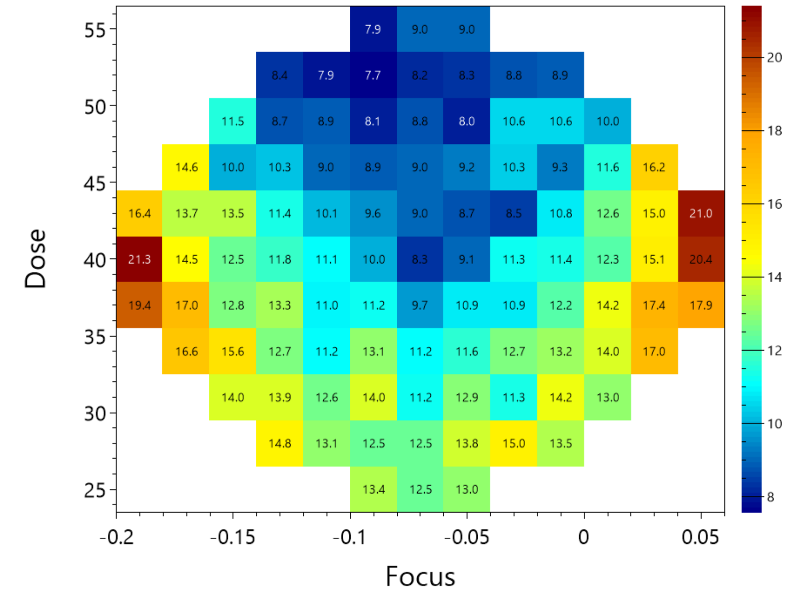


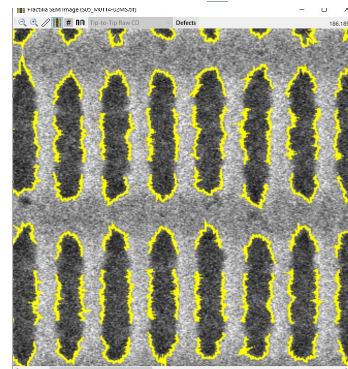
Acceptable PVB contours achieved at nominal dose ± 10%

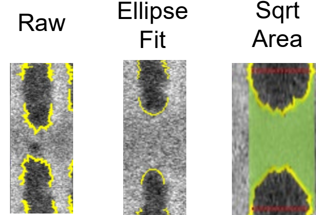
Line-Space and T2T measurement using MetroLER 3.0











- Tip-to-tip Raw CD: closest edge points between tips is susceptible to edge detection noise
- Tip-to-tip Fit CD: closest distance between best-fit ellipses is robust to edge detection noise
- Sqrt(Area) CD: very robust to edge detection noise, but a different measure of "distance"

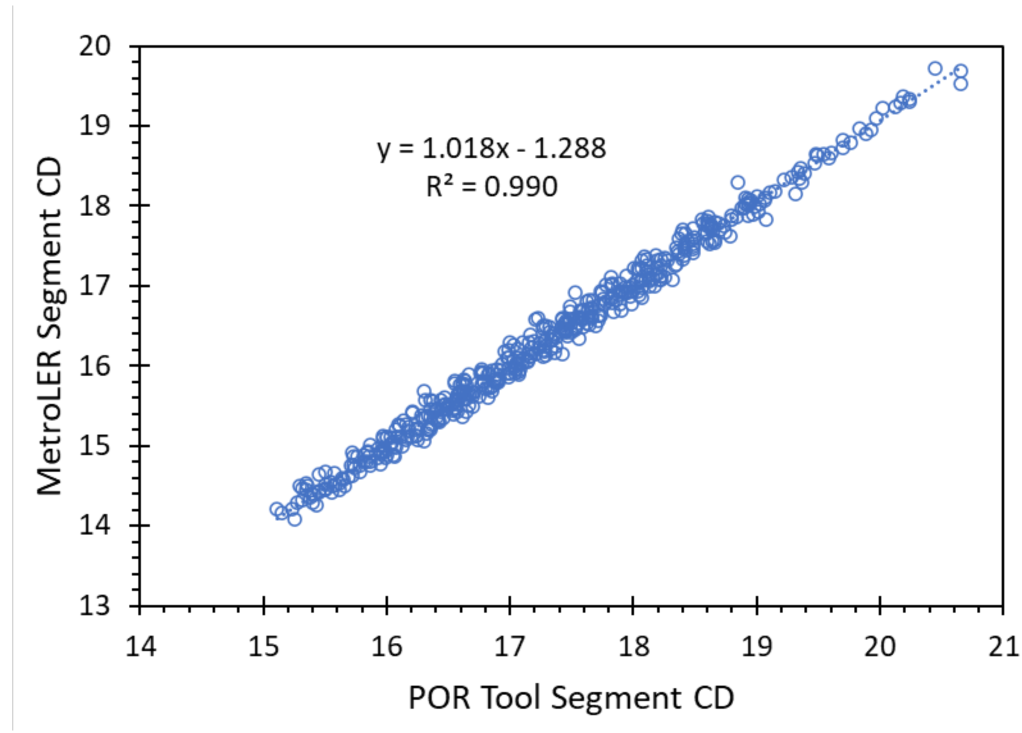
LAM RESEARCH

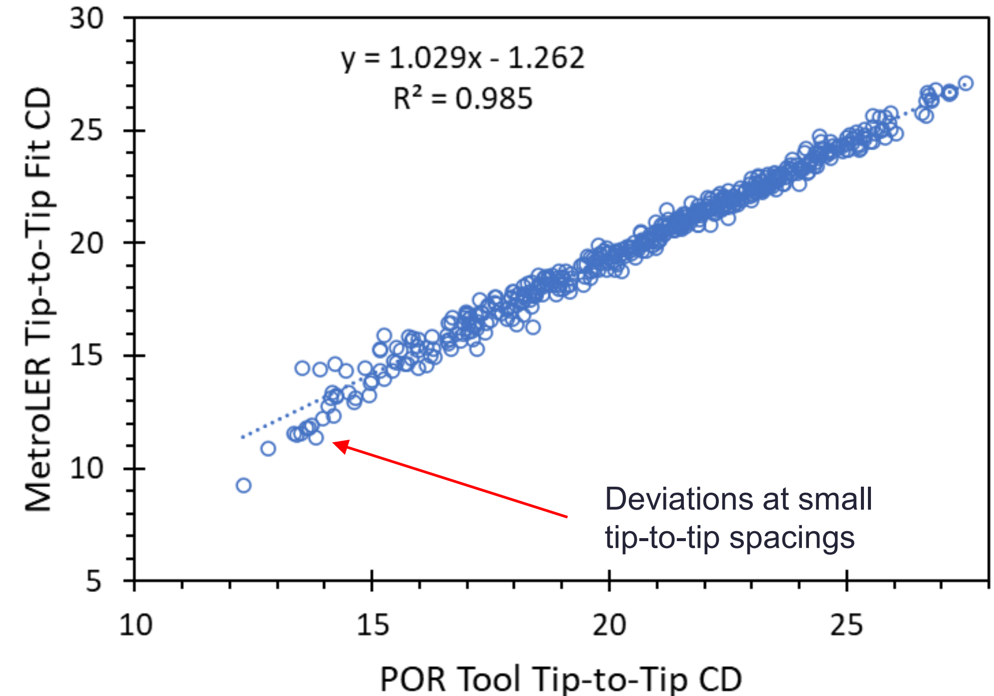
FRACTILIA
COMPUTATIONAL METROLOGY

imec

Comparing POR Tool to MetroLER for CD Measurement

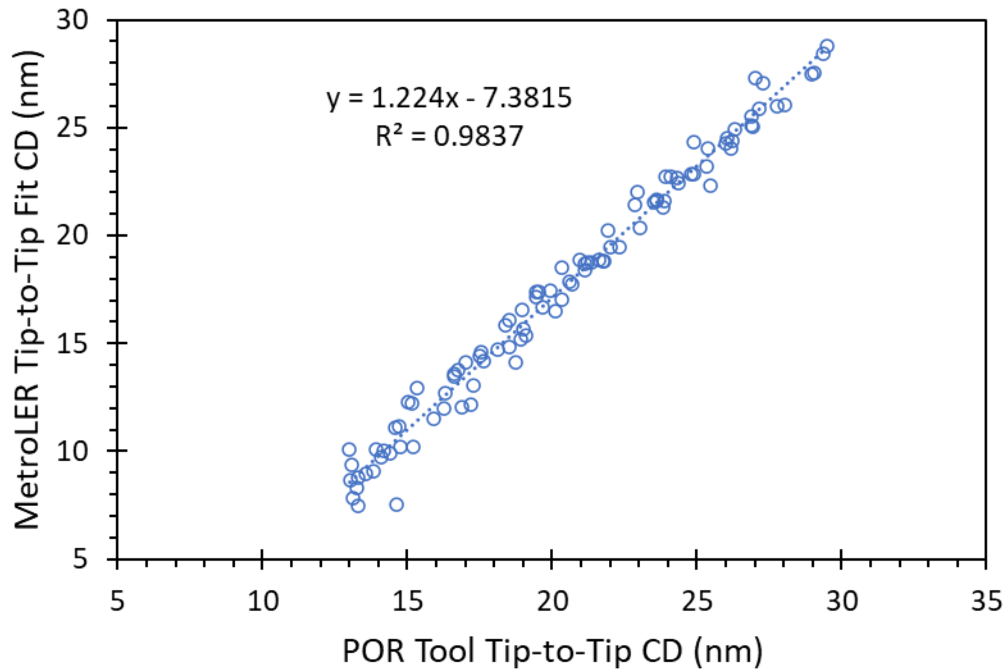
(through dose, at best focus)





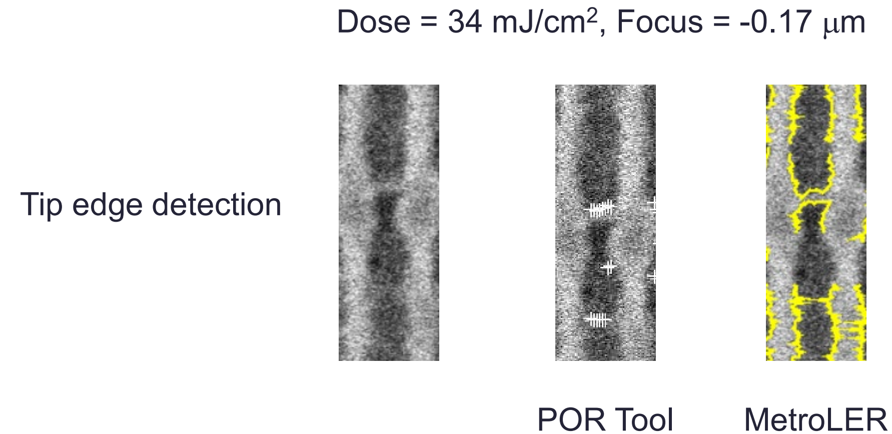
- Good linearity, slope near 1
- Dose Stripe Wafer (dose from 35 to 55 mJ/cm2) at best focus
- Two pitches (28 nm and 30 nm) and three tip-to-tip design spacings
- Average CD for image, 494 images

Comparing POR Tool to MetroLER for FEM Wafer



- Slope significantly different from 1
- FEM Wafer
- Average CD for image, 99 images

Dose = 34 mJ/cm², Focus = -0.17 µm



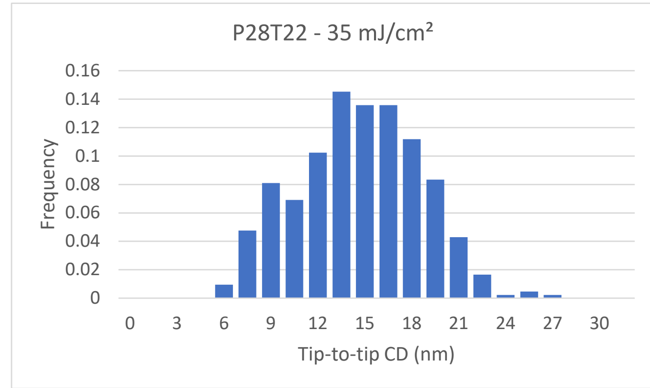
POR tool often misses tip edge detection for misshapen or merged tips
(tips printed at off-nominal focus)

Improvement in T2T CD measurement

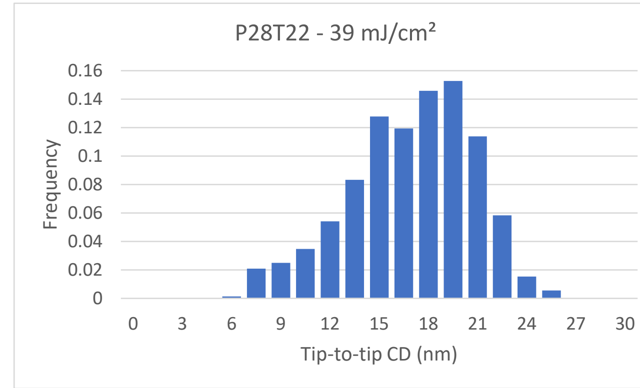
Curved feature edge detection errors: POR tool vs. MetroLER

POR Tool

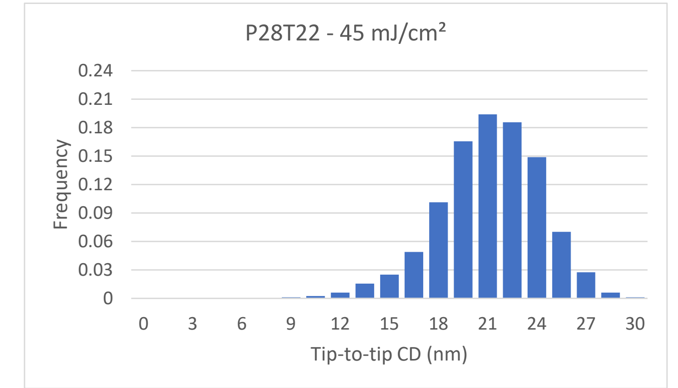
P28–T2T22 Dose 35mJ/cm² / Focus -0.07µm



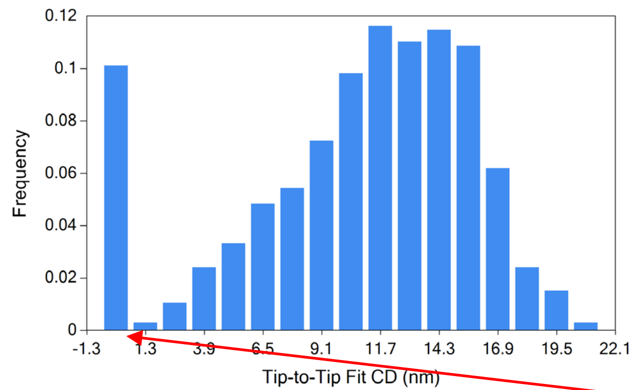
P28–T2T22 Dose 39mJ/cm² / Focus -0.07µm

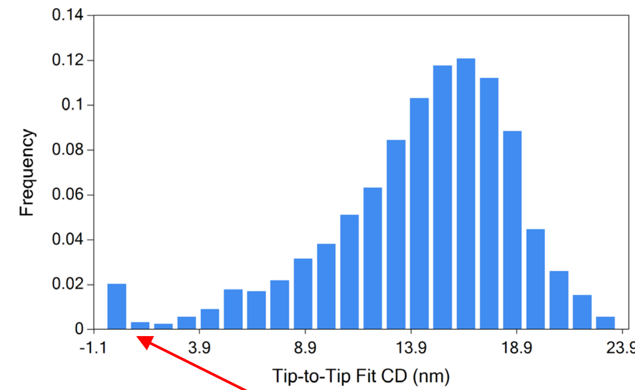


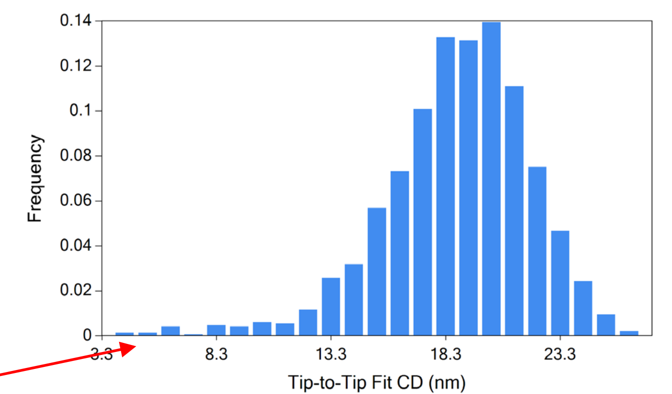
P28–T2T22 Dose 45mJ/cm² / Focus -0.07µm



MetroLER



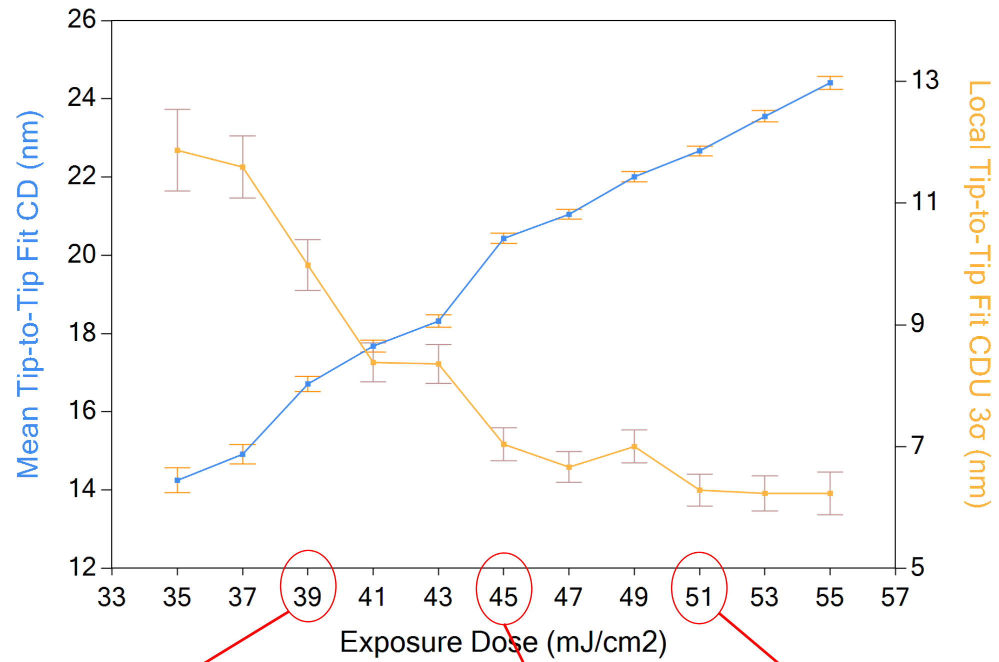


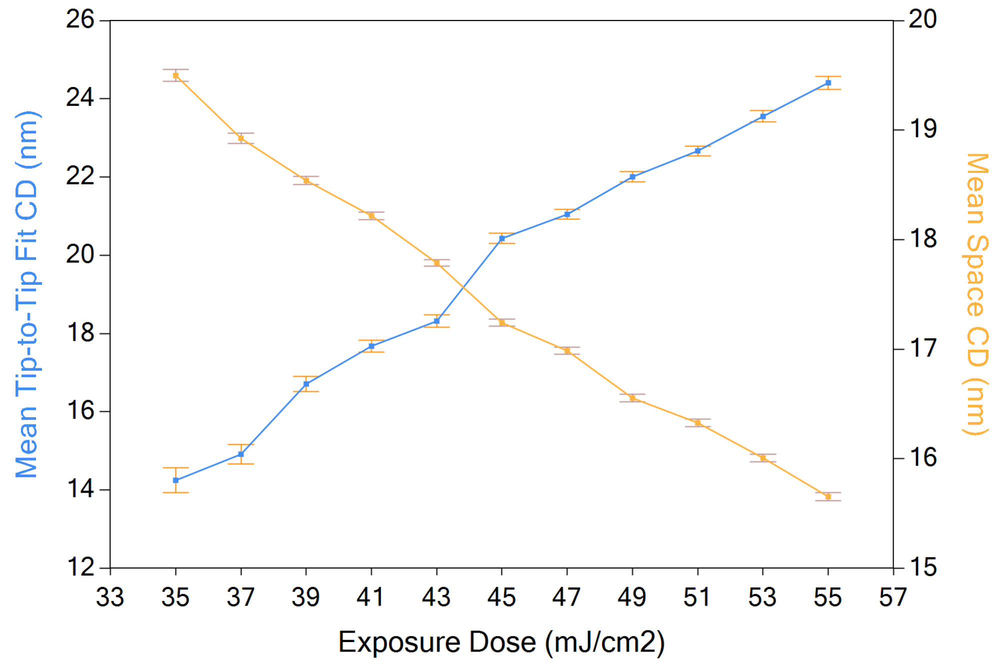


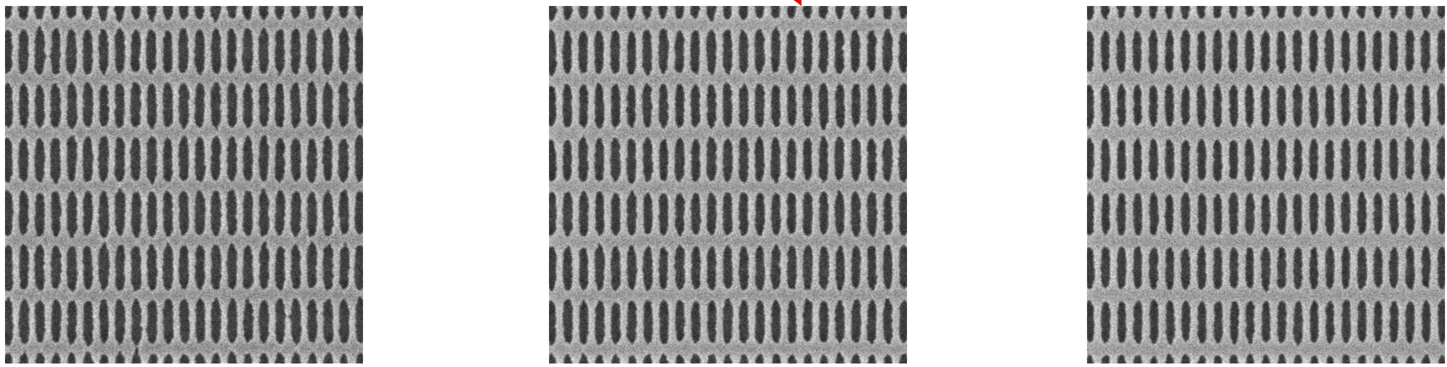
Detection of merged and small-gap tips

LAM RESEARCH FRACTILIA COMPUTATIONAL METROLOGY imec

Optimum litho dose selection (at best focus)







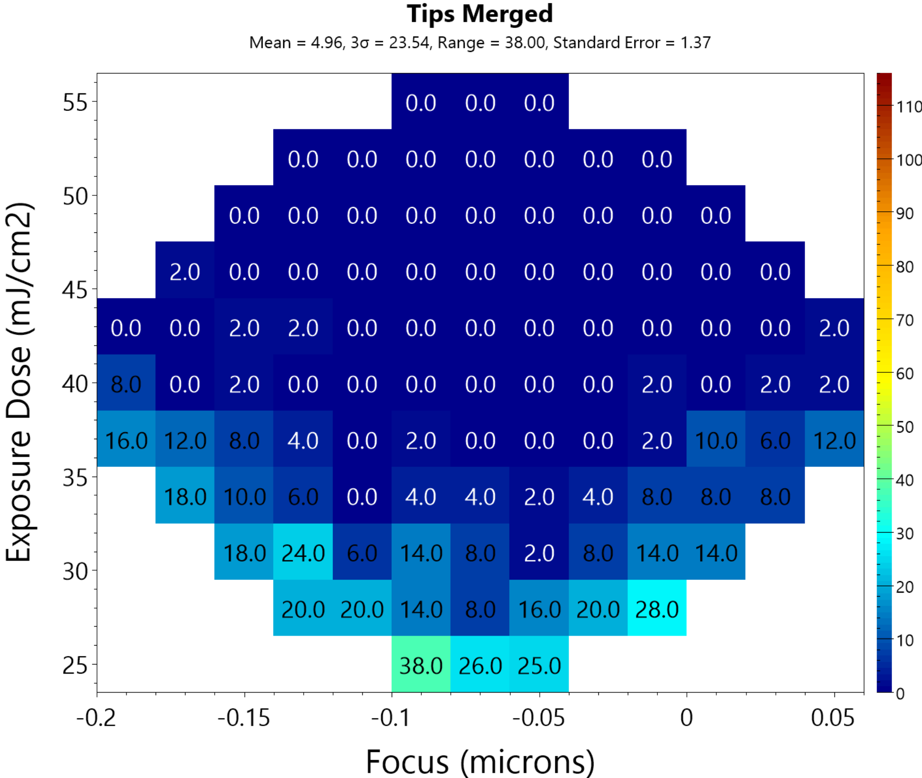
Trade-off between tip-to-tip CD, segment space CD, and stochastic variations such as tip-to-tip LCDU

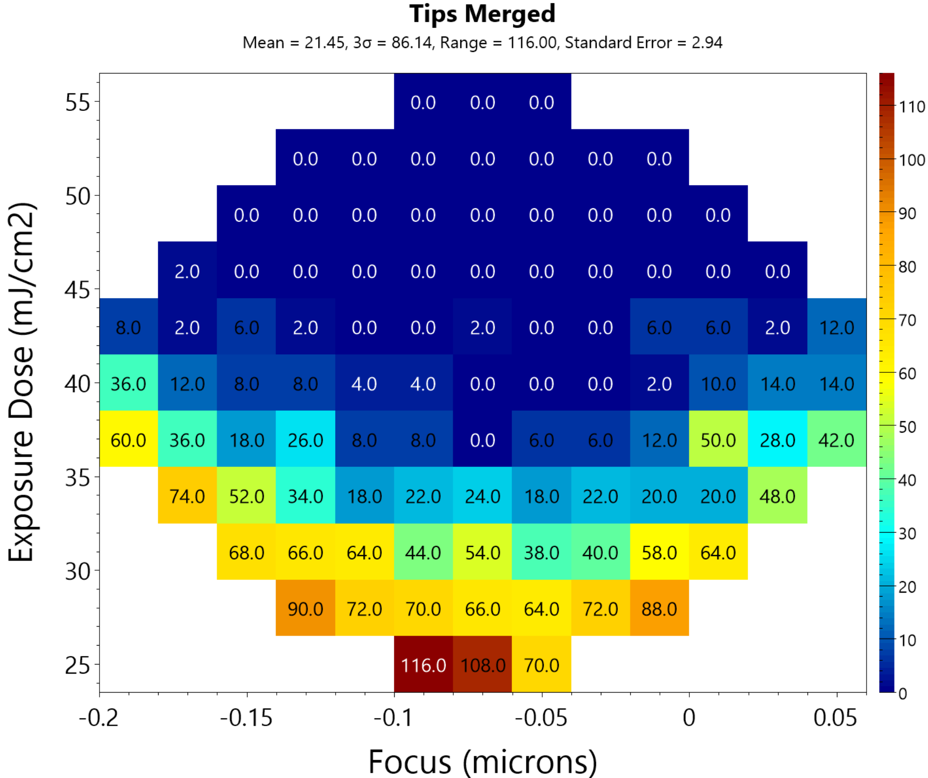
Merged T2T defect measurement - FEM

Define Bridge/Break/Missing/Merged as:
Define defects in: nm
Segment less than width (nm): 10
Tip-to-Tip less than width (nm): 1.5
Height at least this many pixels: 3

Impact of Merged Tip CD Spec

Define Bridge/Break/Missing/Merged as:
Define defects in: nm
Segment less than width (nm): 10
Tip-to-Tip less than width (nm): 5
Height at least this many pixels: 3





= value used in subsequent FEM analysis

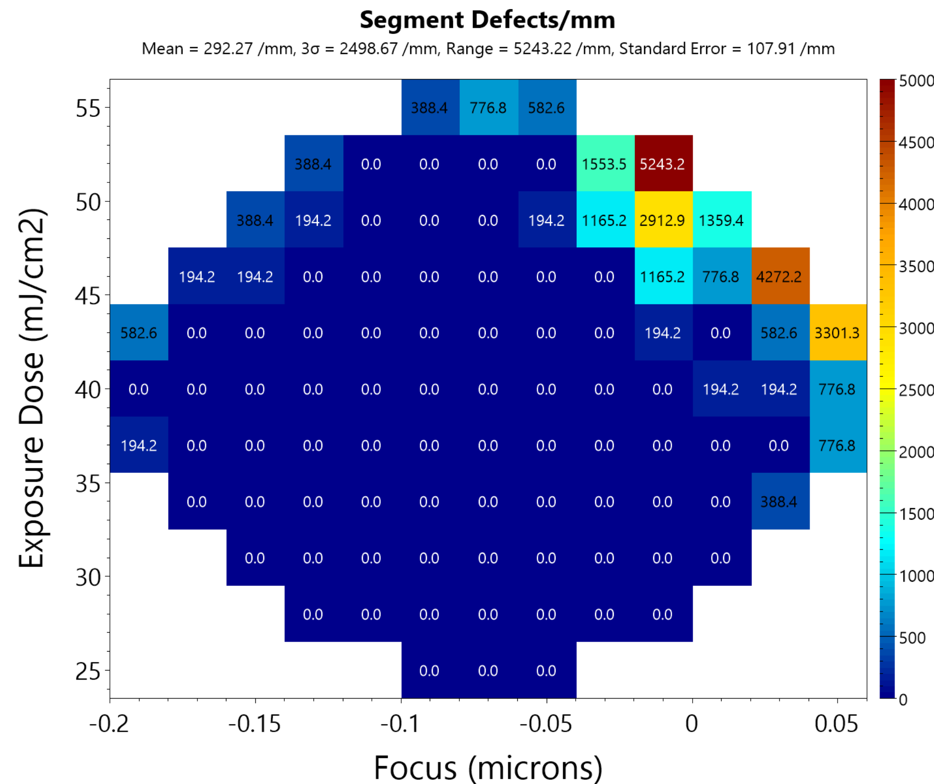
LAM RESEARCH FRACTILIA COMPUTATIONAL METROLOGY imec

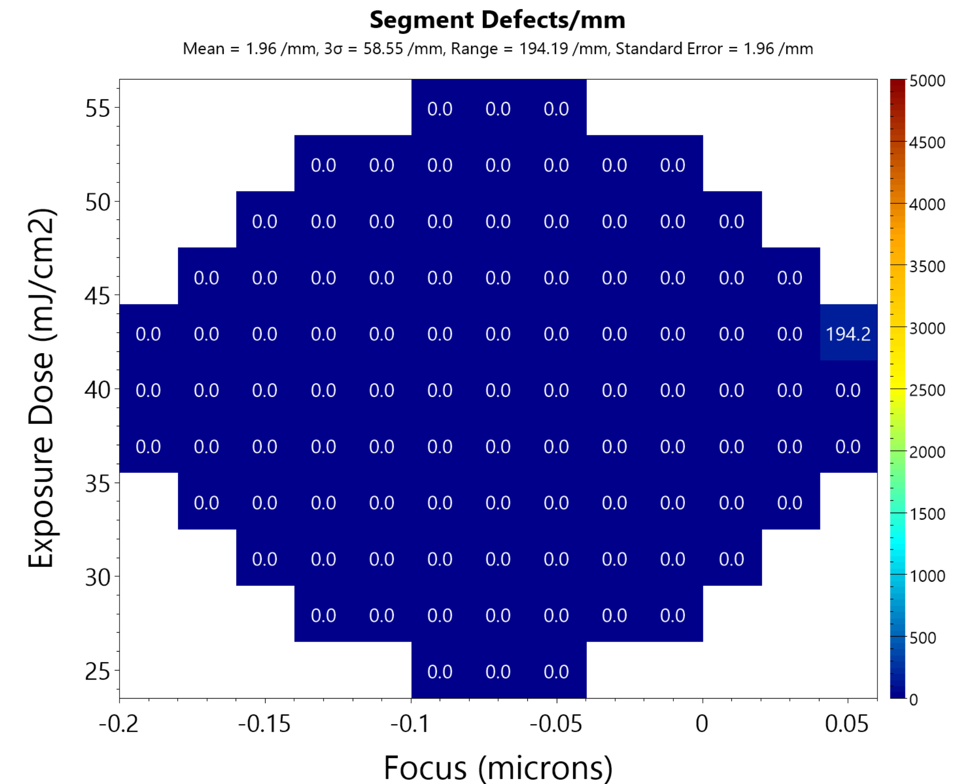
Bridged space defect measurement - FEM

Define Bridge/Break/Missing/Merged as:
Define defects in: nm
Segment less than width (nm): 10
Tip-to-Tip less than width (nm): 5
Height at least this many pixels: 3

← Impact of Bridged Space CD Spec →

Define Bridge/Break/Missing/Merged as:
Define defects in: nm
Segment less than width (nm): 5
Tip-to-Tip less than width (nm): 5
Height at least this many pixels: 3

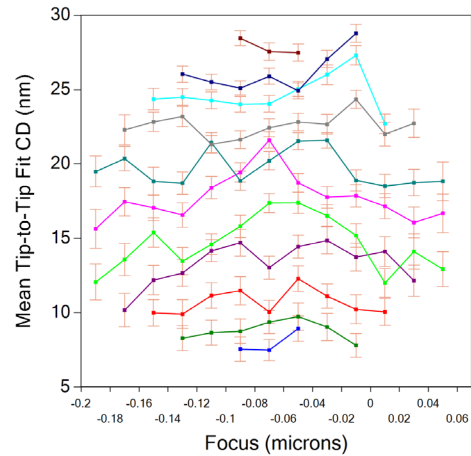


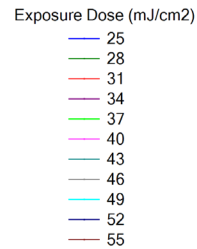


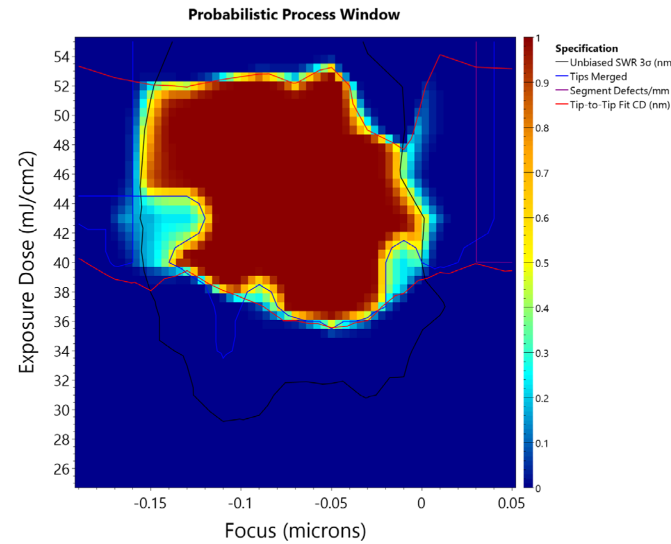
= value used in subsequent FEM analysis

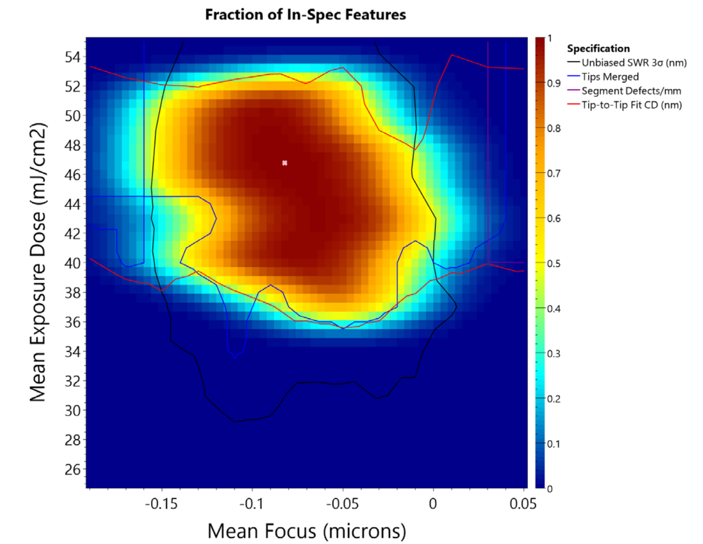
Overlapping LS and T2T probabilistic process window

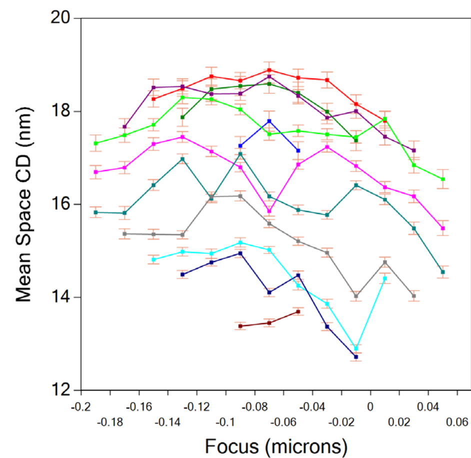
(Paper 12053-14 gave details of the Probabilistic Process Window)

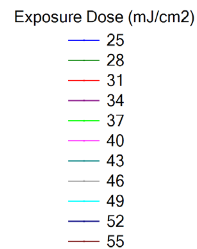


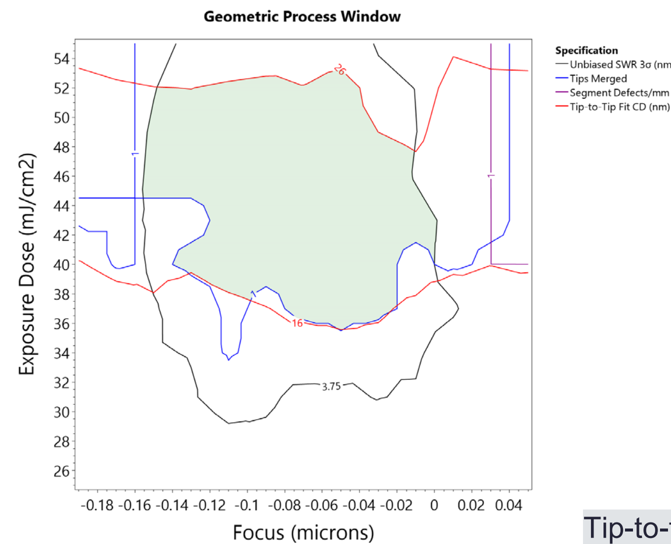


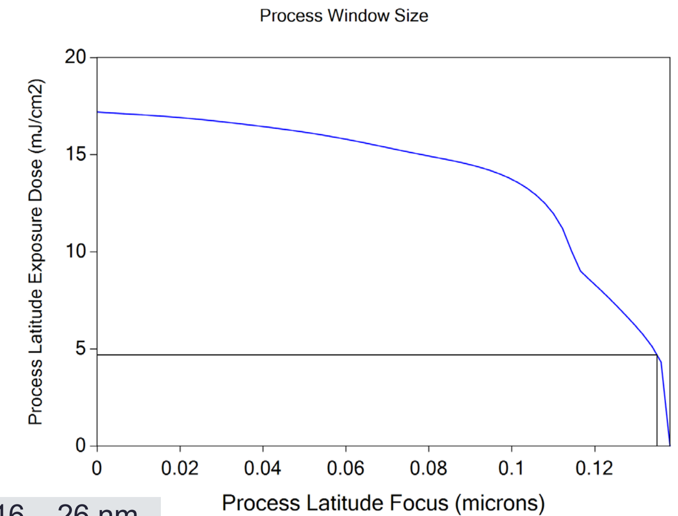












Tip-to-tip CD: 16 – 26 nm
Unbiased SWR: < 3.75 nm
Defectivity = 0

LAM RESEARCH

FRACTILIA
COMPUTATIONAL METROLOGY

imec

Conclusions

- Lam dry deposited dry developed EUV photoresist enables <20nm T2T 0.33NA single exposure patterning of <32nm L/S features with wide process window
- Fractilia's MetroLER tool offers improved edge detection for curved features compared to Lam's current POR tool
  - Better detection of small and misshapen line-end tips
- Probabilistic process window provides accurate assessment for both traditional and stochastic metrics
  - Careful attention to specs used and trade-offs with dose are required

Acknowledgments

Authors wish to express their sincere gratitude to the members of Lam Dry Photoresist Product Group for their contributions in processing wafers at Fremont and imec locations. Special thanks goes to Lam Fremont Metrology team for insightful discussions on metrology challenges.