Automated SEM Metrology Use Cases for InSPEC

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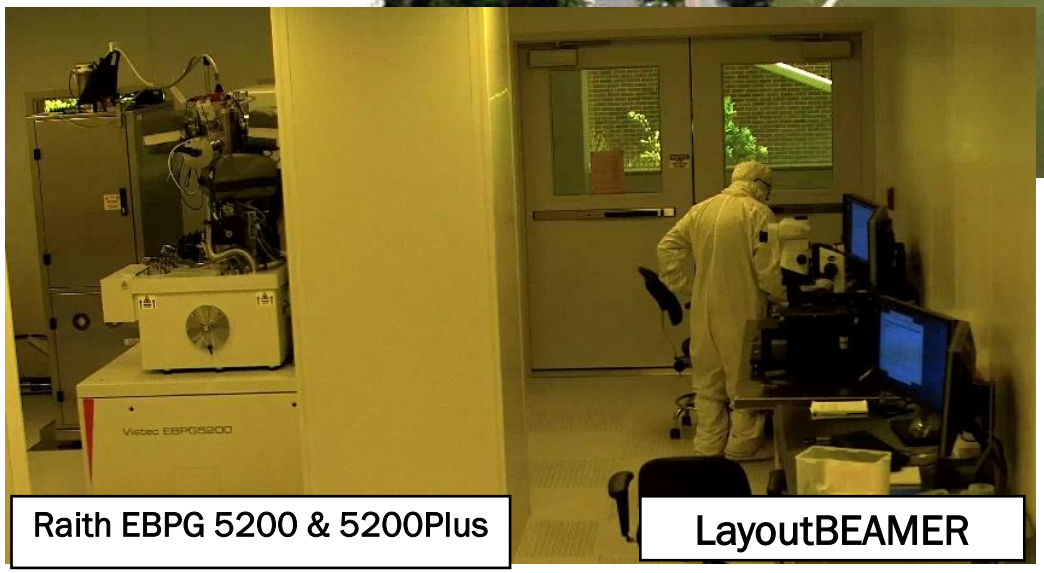


Raith EBPG 5200 & 5200Plus

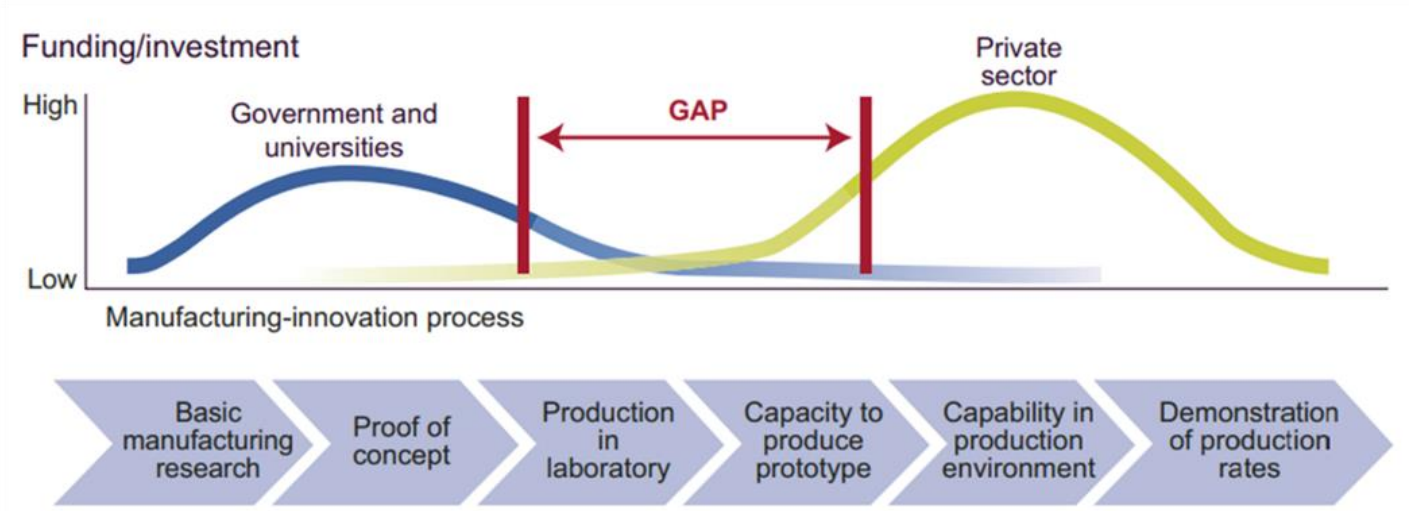
LayoutBEAMER

Millennium Science Complex

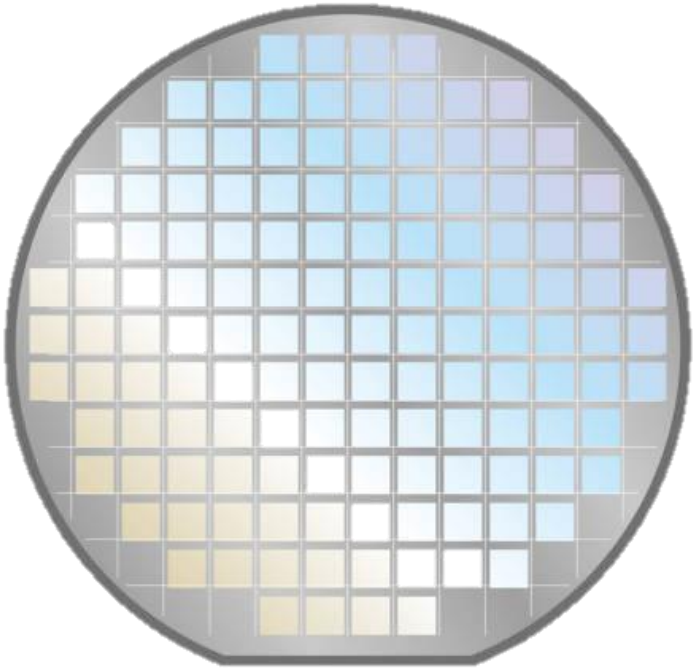
- Located at University Park Campus
- 248,000 sq. ft. interdisciplinary Materials and Life Sciences Building
- 10,000 sq. ft. class 100/1000 clean room with 6500 sq. ft of support space

Motivation for Automated SEM and Measurements

- Greater work in the gap between research and manufacturing
- Growing need for large data sets
- Correlation of results require data to be organized
- AI presents opportunities to utilize this data in new ways



Seeing more full wafers in university research



Up to 200 mm wafers

Image from https://community.arm.com/

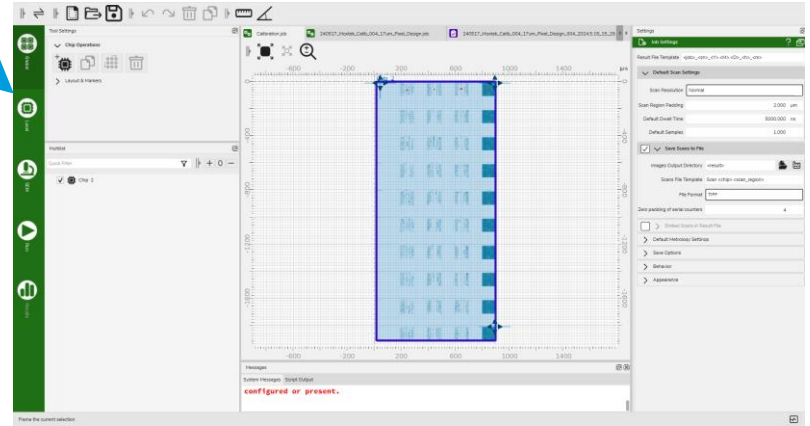
Automated Design Driven SEM Imaging

Hardware Interface I/O

Serial Port

InSPEC

GDSII



Application Examples of Inspec

- **Process Calibration**
- Overlay Measurement
- Line / Space or Grating Measurement
- Device CD - Transistor Channel Length
- Contour Extraction – Shape fidelity / Blur extraction
- Complex Pattern – Meta Lens

Calibration Example

- HSQ resist (similar to last years talk)
- Process Conditions:
  - The wafer is 8inch coated with 30nm of LPCVD Si3Nx
  - The resist coating:
    - From Dischem Inc - H-SiQ 6%
    - Dynamic apply
    - 2500 rpm for 45 sec
    - Bake @ 120°C for 2 min
  - Exposure dose was 1025μC/cm2
  - Develop is 10 min at room temperature with MF-312
  - DI water rinse

Example process flow

Initial Test Pattern Exposure

TRACER

BEAMER

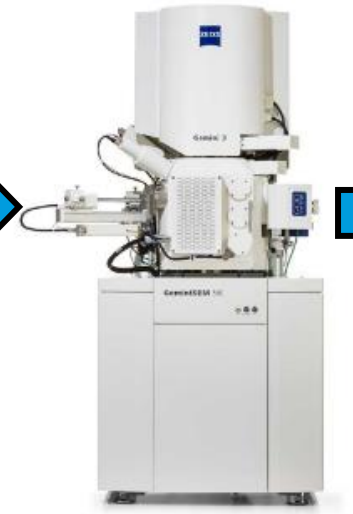
SEM Imaging

InSPEC

HW

I/O + Scan I/F

SEM



Measure & Calibration

TRACER

InSPEC

PEC-Fracture & Exposure Actual Design

BEAMER

Image & Measure

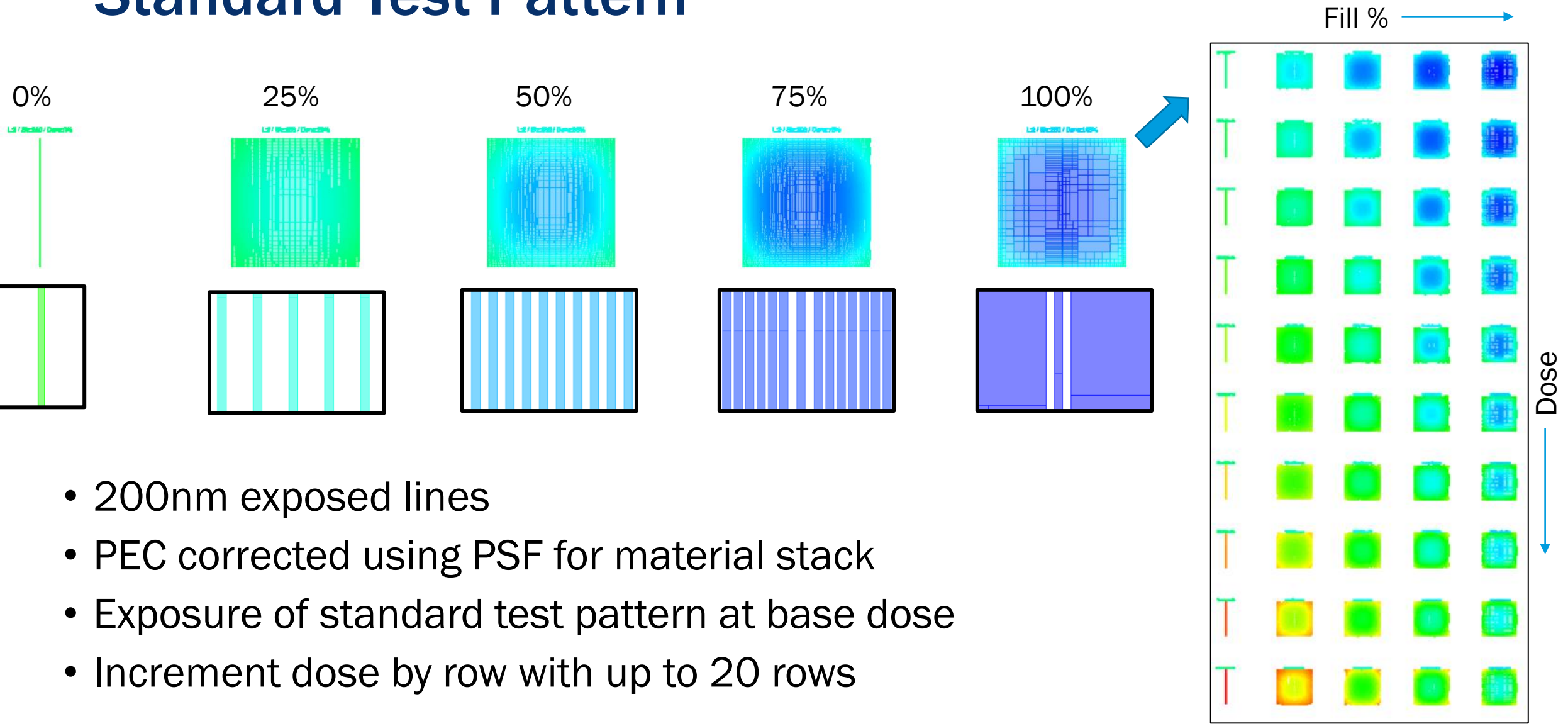
InSPEC

HW

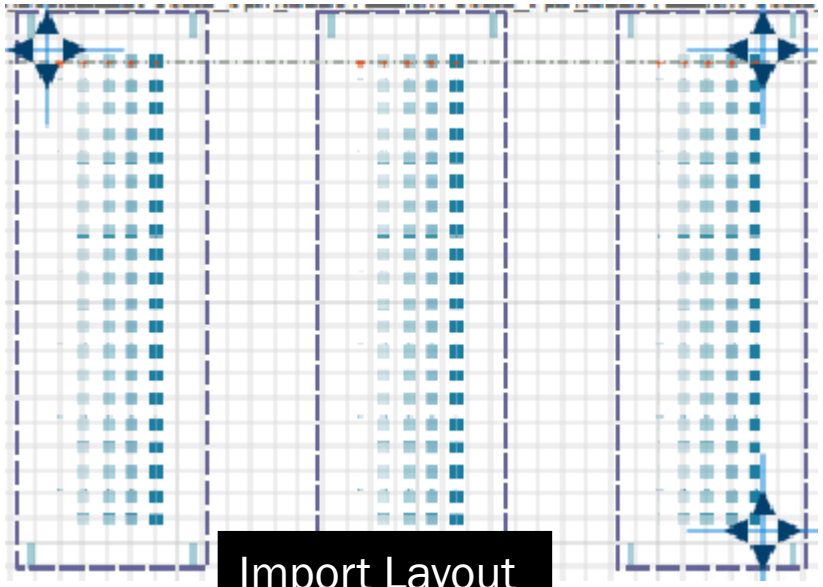
I/O + Scan I/F

SEM

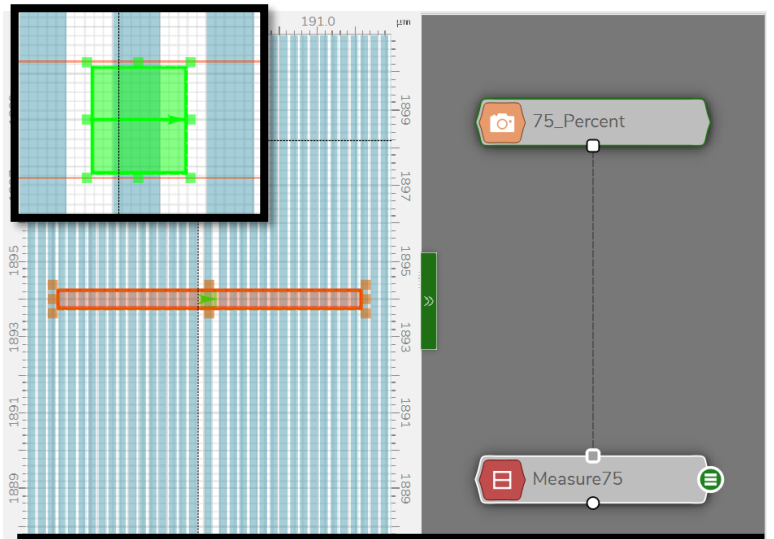
Standard Test Pattern



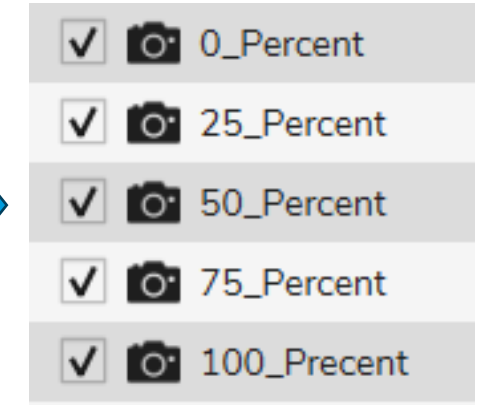
- 200nm exposed lines
- PEC corrected using PSF for material stack
- Exposure of standard test pattern at base dose
- Increment dose by row with up to 20 rows



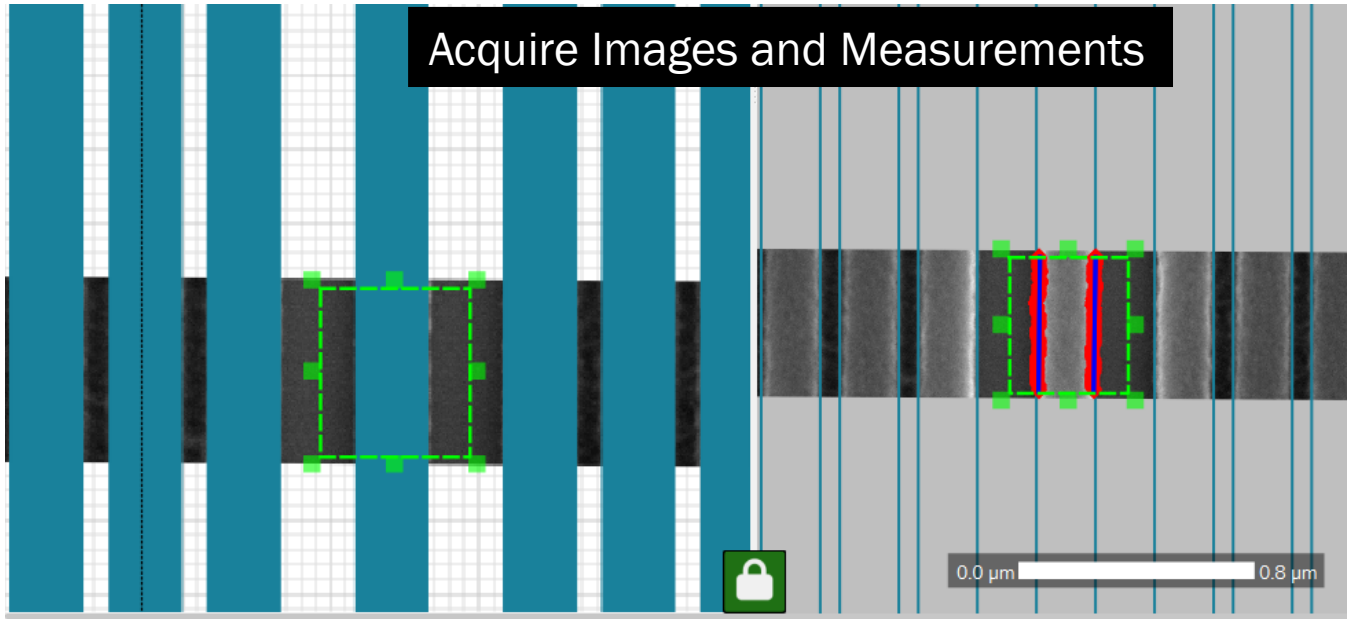
Import Layout



Define Images and Measurements



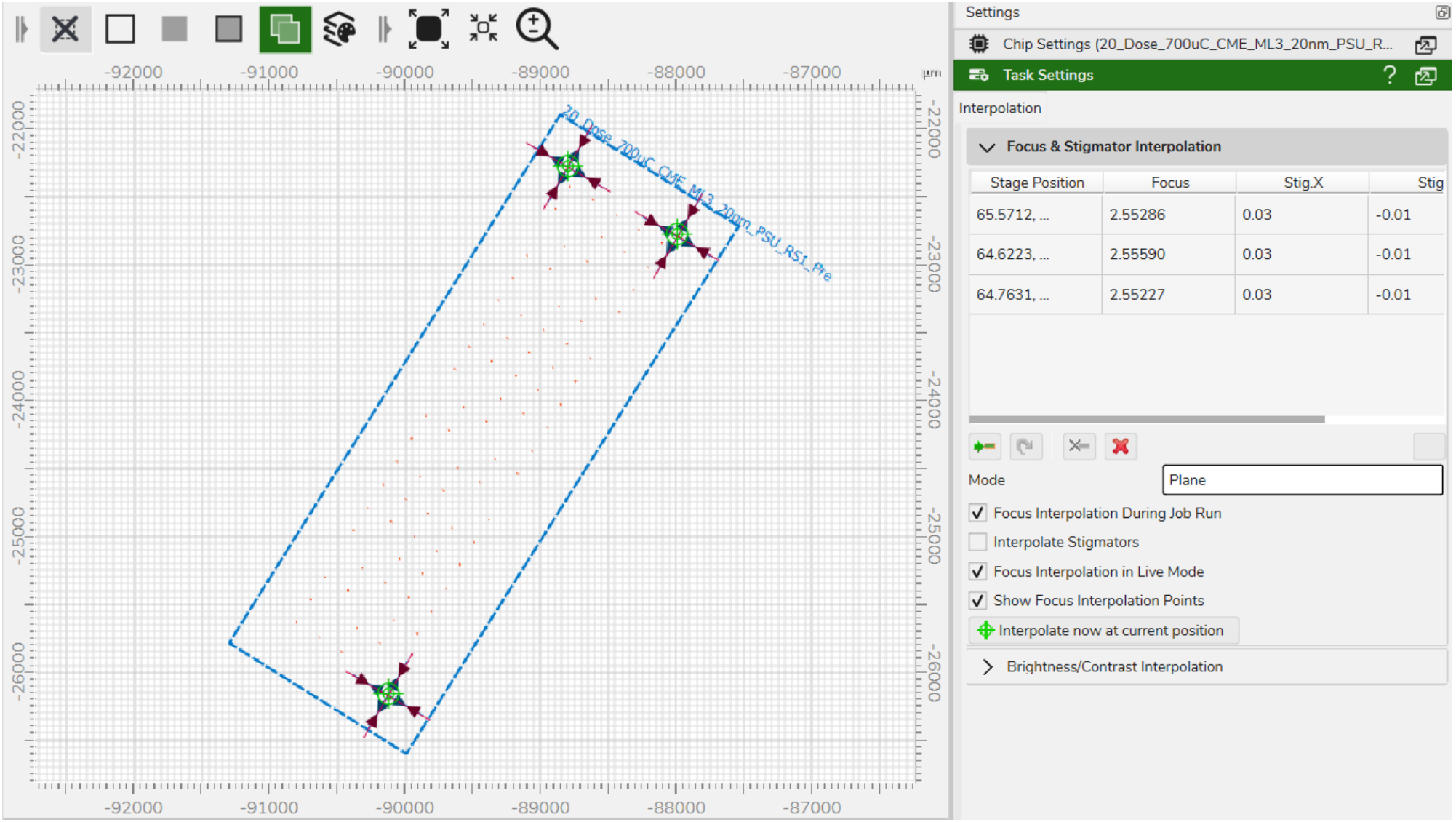
Multiple sites per Chip



Acquire Images and Measurements

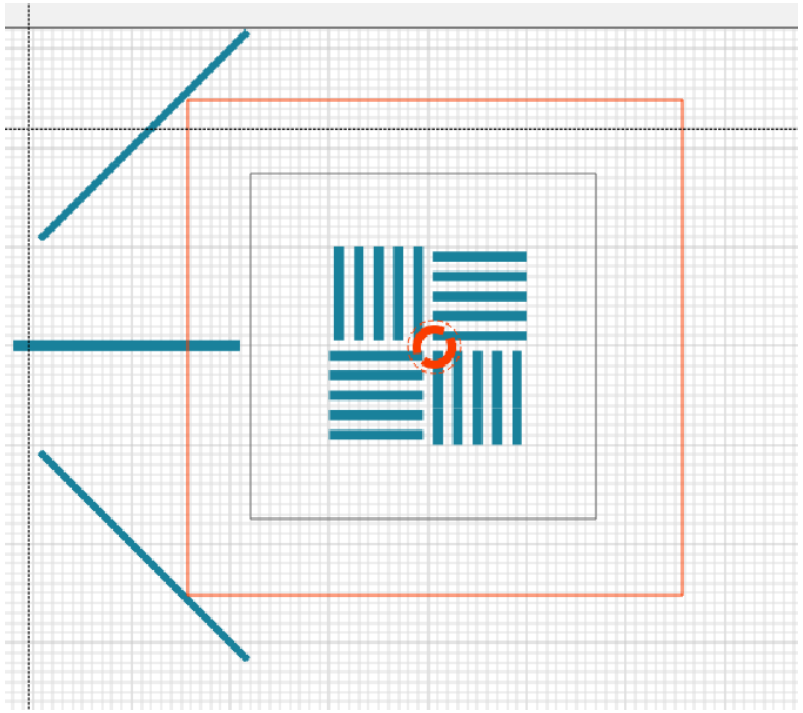
InSPEC

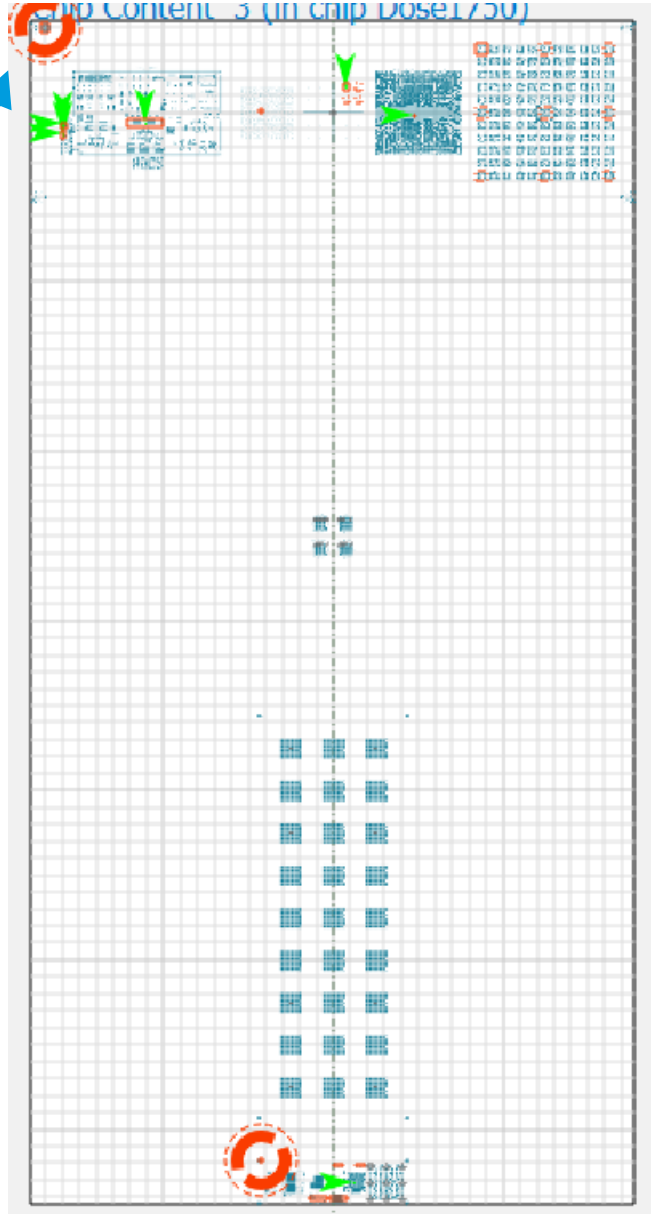
Focus Map (manually correct for tilt/bow)

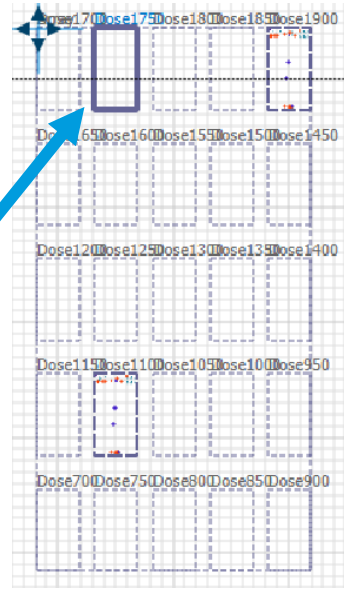


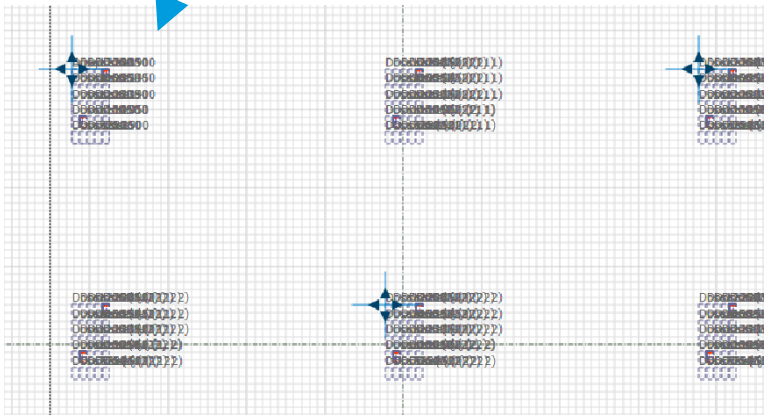
Use of Autofocus

Automatic adjustment of focus during measurements

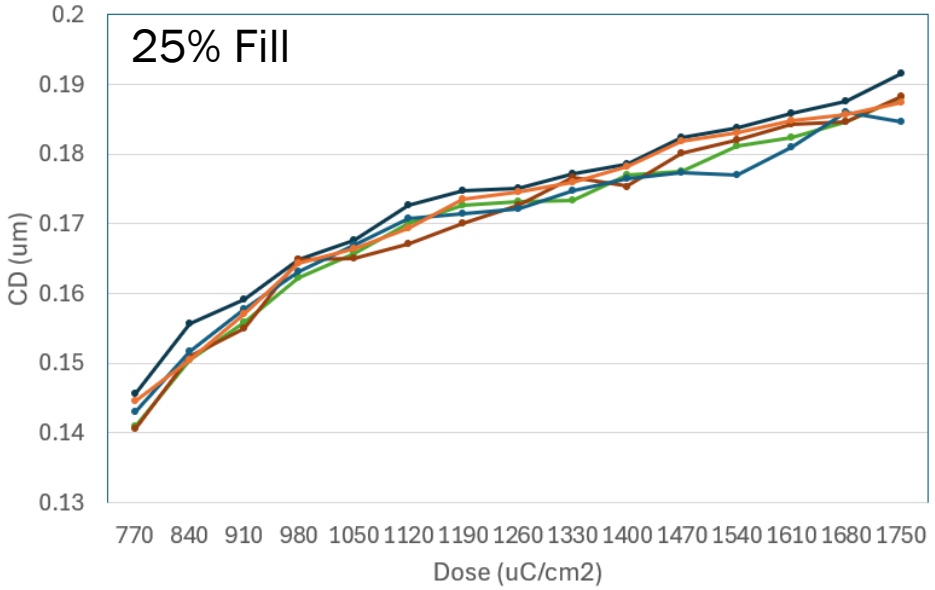


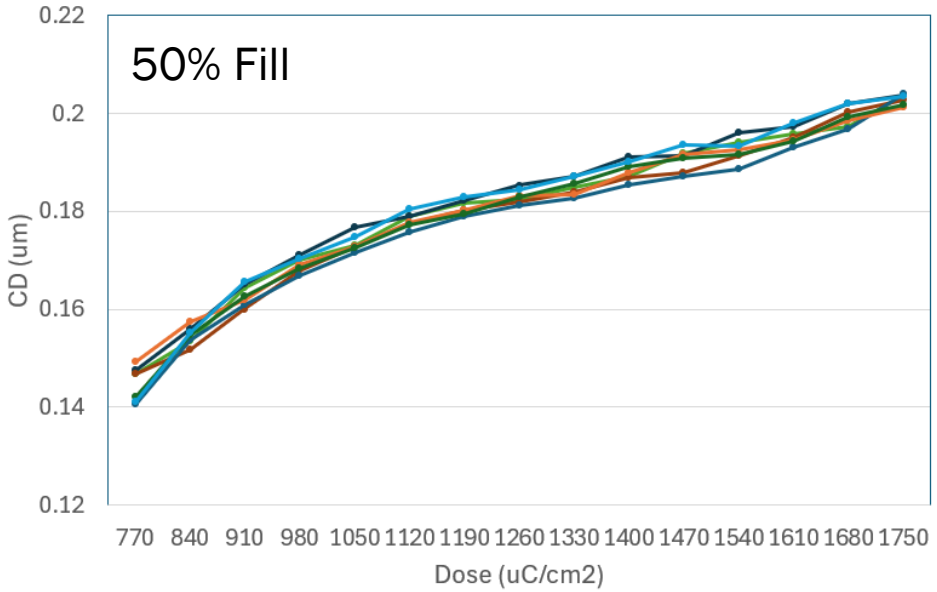




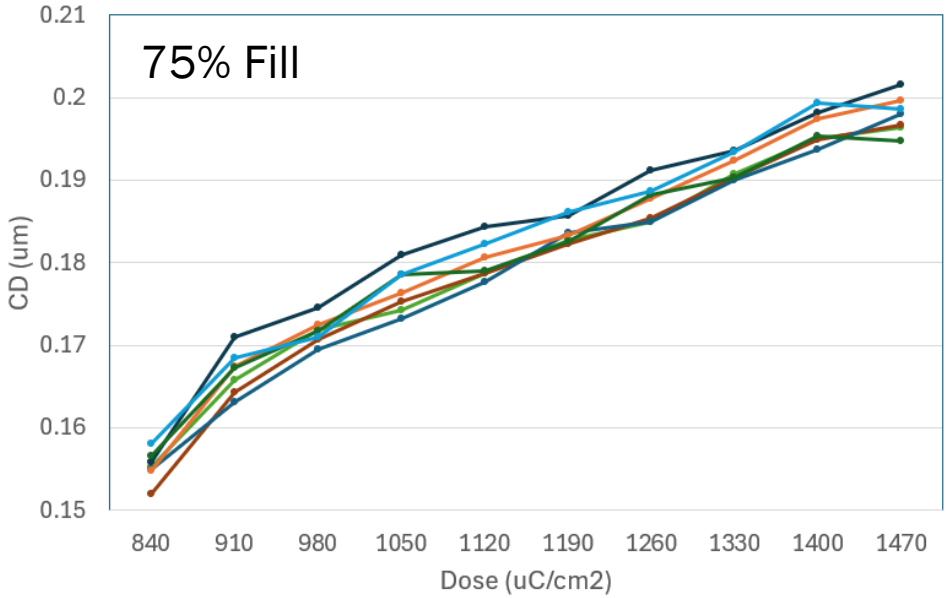


Quickly Survey of Results



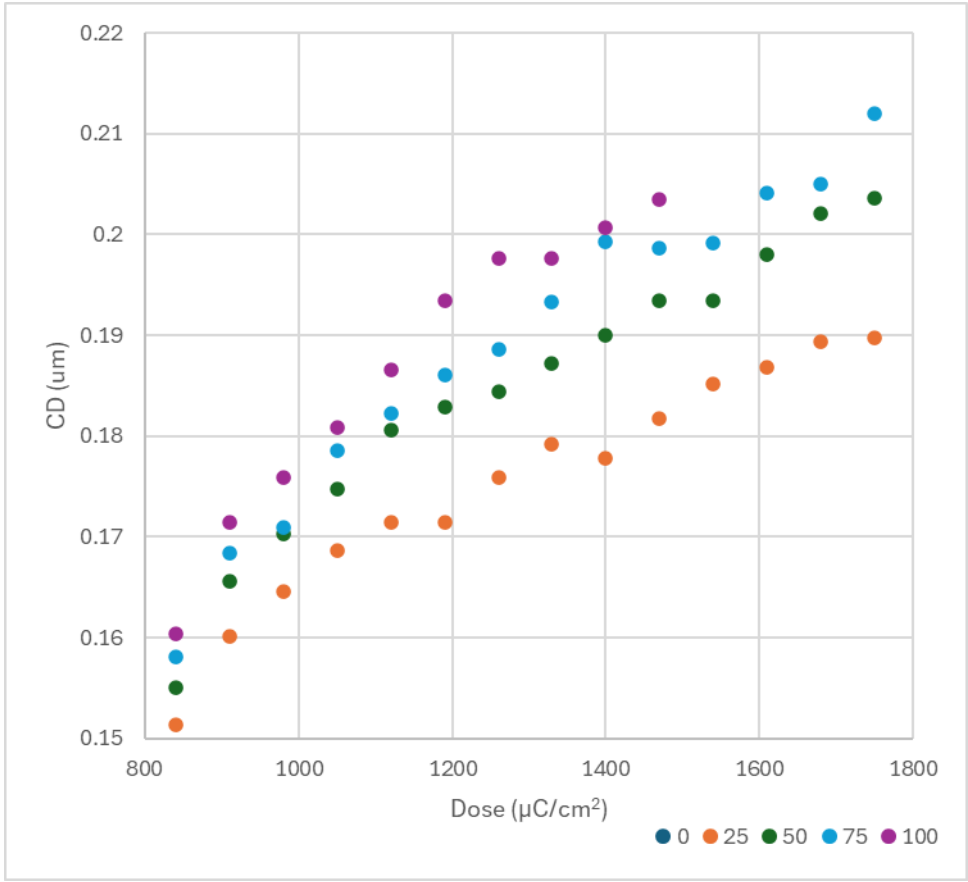


- Quickly survey data to look for deviations
- Then fit any deviations in Tracer to identify changes
- This is example of job looking at various pattern preparation variables (Healing, fracturing modes, etc) and in this case no significant difference which was expected



Raw Proximity Corrected Data used for Calibration

	Fill Fraction				
Dose	0	25	50	75	100
840	0.155	0.151	0.155	0.158	0.160
910	0.160	0.160	0.166	0.168	0.171
980	0.164	0.165	0.170	0.171	0.176
1050	0.166	0.169	0.175	0.179	0.181
1120	0.169	0.171	0.181	0.182	0.187
1190	0.172	0.171	0.183	0.186	0.193
1260	0.174	0.176	0.184	0.189	0.198
1330	0.175	0.179	0.187	0.193	0.198
1400	0.175	0.178	0.190	0.199	0.201
1470	0.177	0.182	0.193	0.199	0.204
1540	0.179	0.185	0.193	0.199	
1610	0.180	0.187	0.198	0.204	
1680	0.180	0.189	0.202	0.205	
1750	0.182	0.190	0.204	0.212	



Calibration in Tracer

Use additional mid range fit term

The PSF calibration now features an additional fit option to consider a mid-range influence during the optimization. It can be activated by checking **Use additional mid range fit term** in the Calibration menu. It can be used in combination with analytical PSF and PSF from archive. The calibration result can be exported for usage in the **BEAMER** PEC module. This setting is mainly applicable when using HSQ resist. When using HSQ resist even after PEC application, a CD - dose dependency which should have been corrected by PEC was observed. Using the mid range correction mitigates this effect.

Data

	A	B	C	D	E	F
1	Target CD	200	200	200	200	200
2	Density [%]	0.000	25.000	50.000	75.000	100.000
3	Dose [uC/cm^2]	Mea. CD [nm]	Mea. CD [nm]	Mea. CD [nm]	Mea. CD [nm]	Mea. CD [nm]
4	900	0	0	0	0	158.2
5	990	0	159.2	0	170.6	177.2
6	1080	152.2	167.4	0	179.5	186.3
7	1100	155.3	162.4	176.9	184.3	190.8
8	1170	154.2	170.9	181.3	189.2	197.8
9	1210	163.3	172.2	182.8	191.7	202.9
10	1260	159.9	176.3	190.4	201.9	216.7
11	1320	168.3	177.4	188.4	198.2	0
12	1350	166	181	194.4	205.2	0
13	1430	169.8	180.9	196.5	0	0
14	1440	172.8	183.7	197	210.7	0
15	1530	174.3	185.2	199.3	0	0
16	1540	175.3	187.4	209.9	0	0

Add Dose | Add Dataset | Remove | Import... | Export...

Calibration

Input Data

PSF parameter for calibration

Use PSF from archive

2D-PSF: Substrate_Si_Thickness_70000 | Local Archive... | Global Archive...

Use analytical PSF

Beta [nm]: 21878 Eta: 0.74

Gamma [nm]: 0 Nu: 0.00

Optimal contrast [%]: 100 / 0 : Uniform clearing [%]

Calibrated model

From CC... Resist Contrast: 2.50

Thickness [nm]: 200

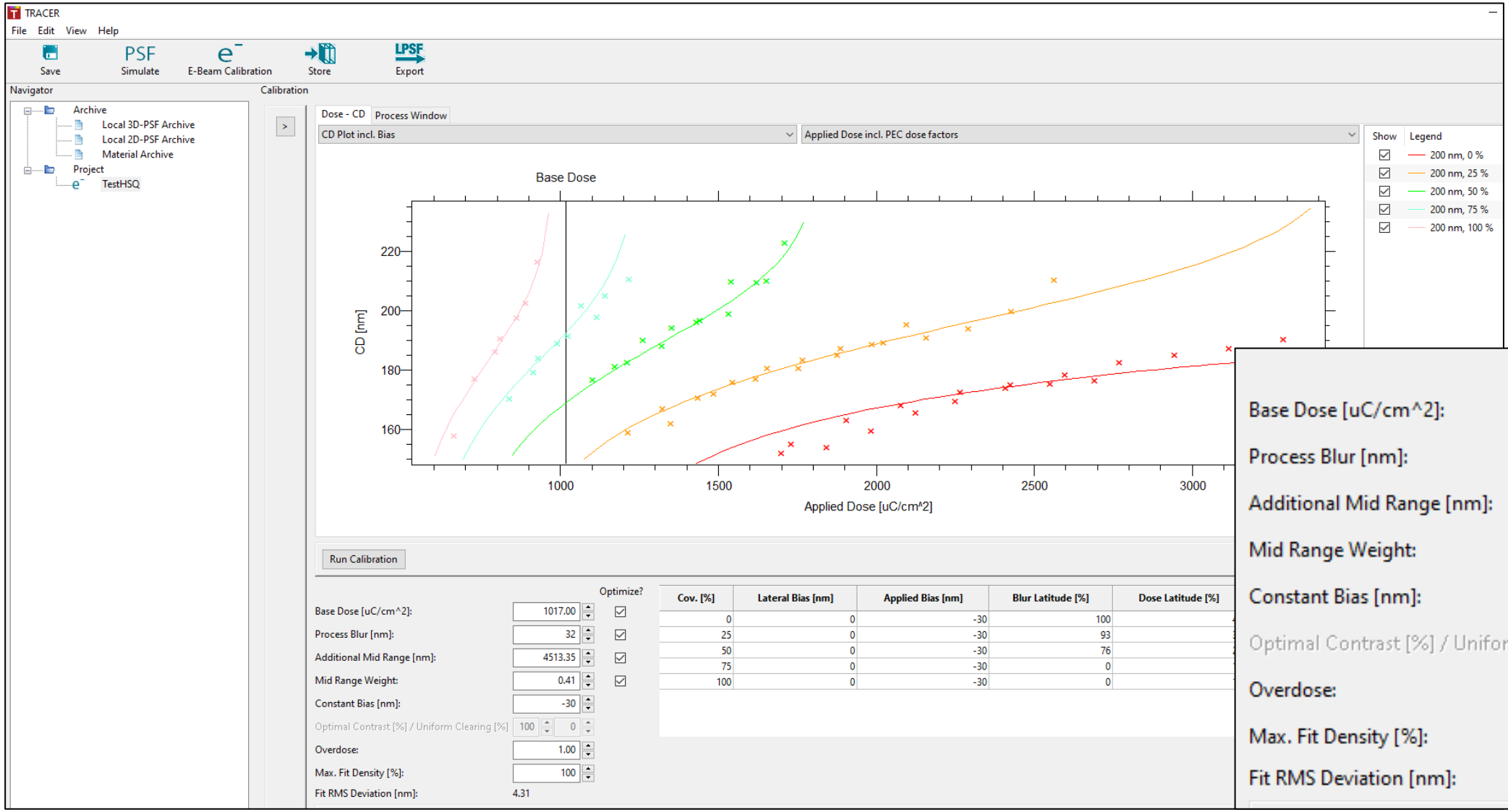
Threshold D0 [uC/cm^2]: 500.00

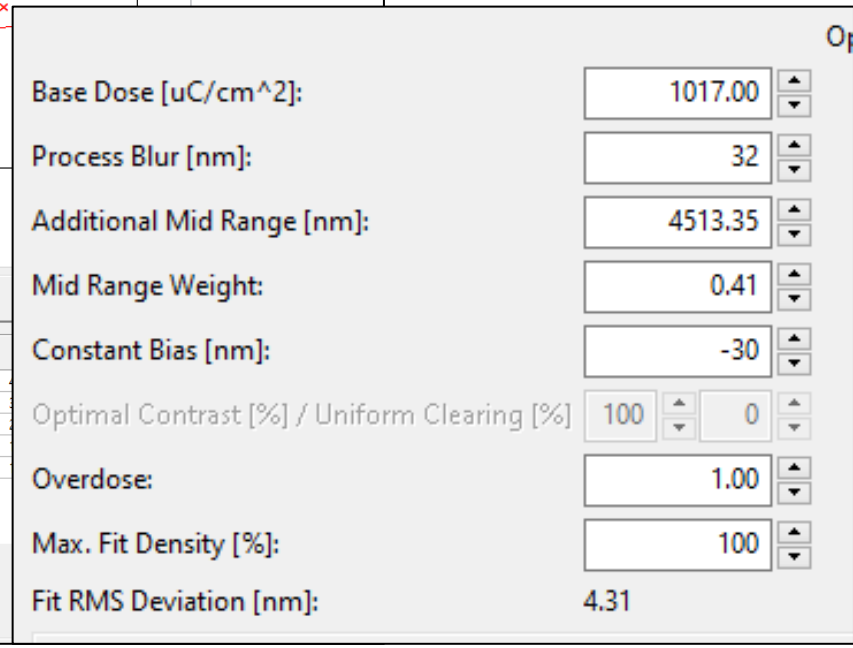
Use additional mid range fit term

Data Properties

Proximity Effect Correction applied

Calibration in Tracer

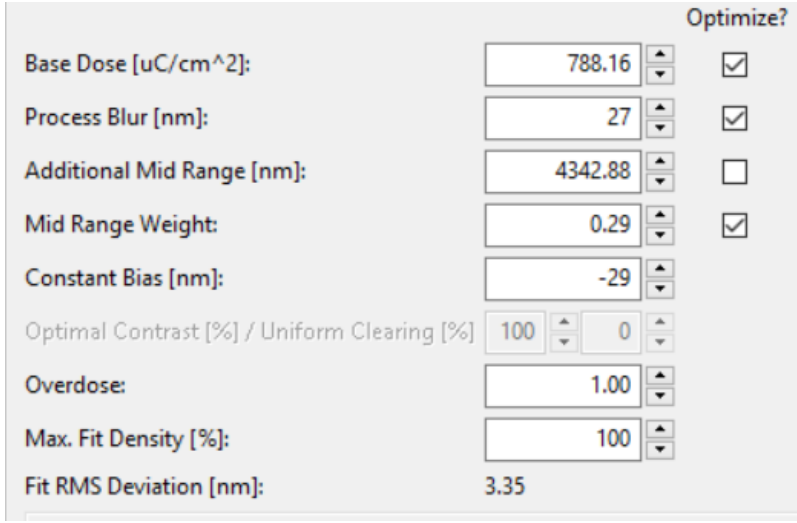
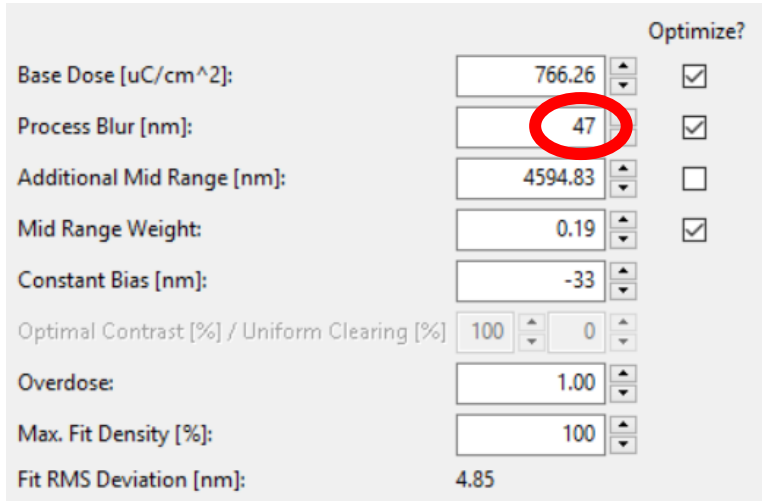
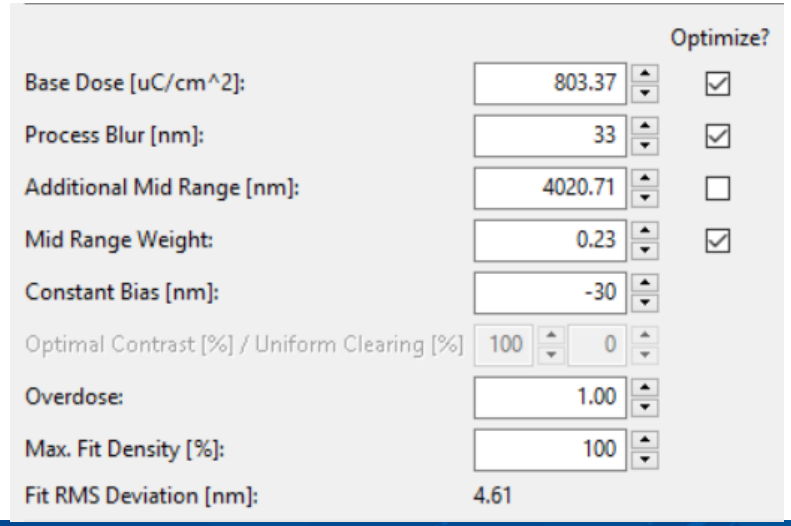




Looking at difference between exposure conditions

Exposure Tool

Beam Step Size / Beam Current

	A205	A270
10nm		
20nm		

Application Examples

- Process Calibration
- **Overlay Measurement**
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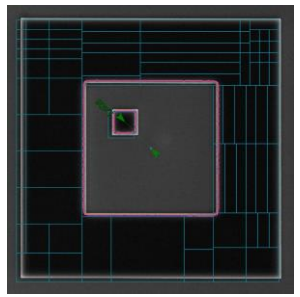
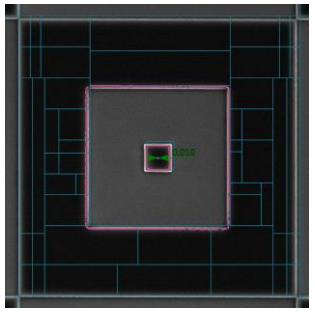
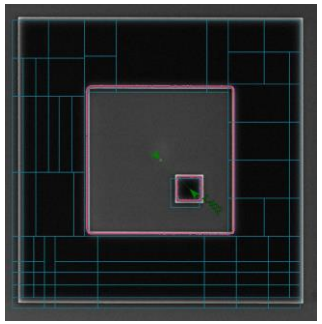
- Device CD - Transistor Channel Length
- Contour Extraction – Shape fidelity / Blur extraction
- Complex Pattern – Meta Lens

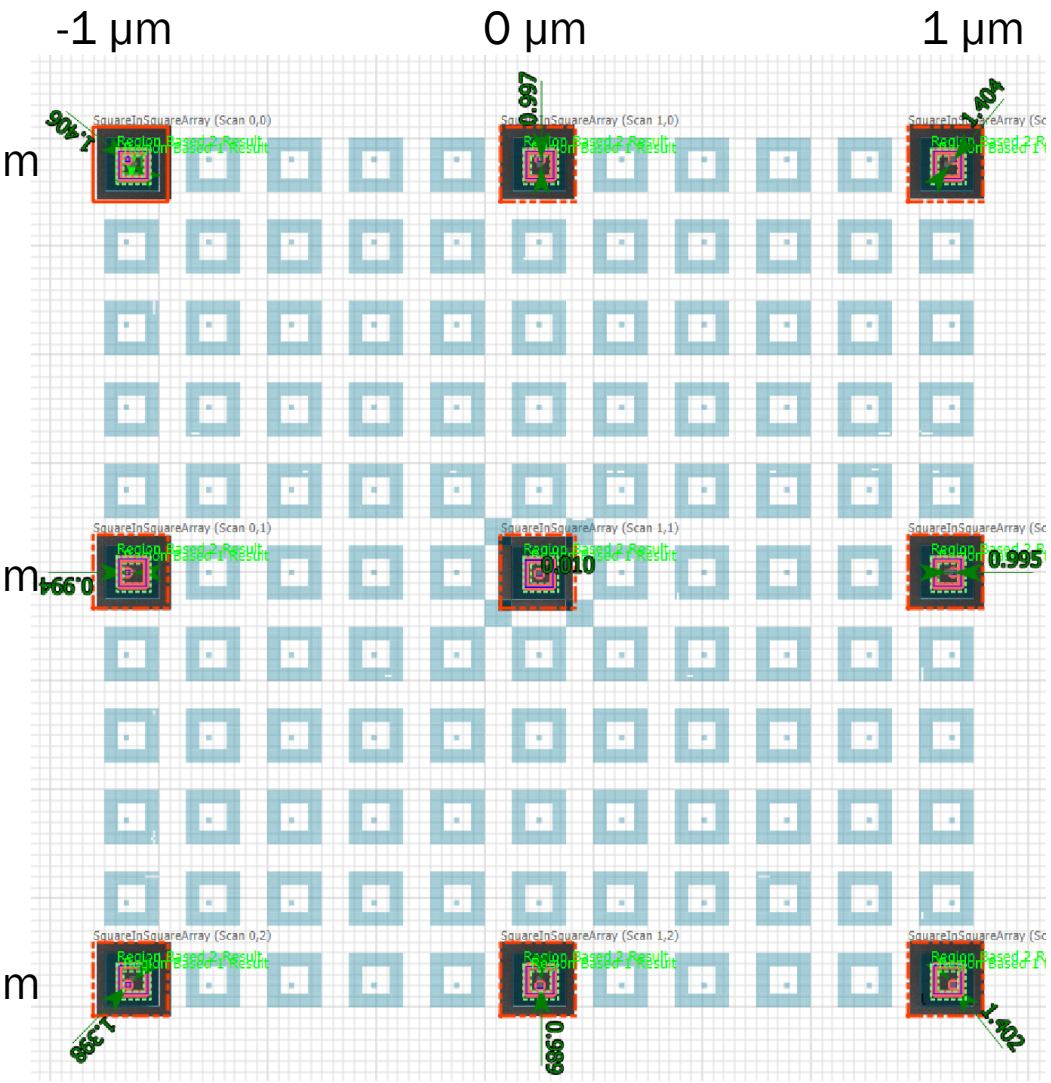
Placement Analysis

- Utilize box in box structure to find relative placement between layers
- Can use to find:
  - Overlay/alignment accuracy
  - Field distortion
- Array of intentional shifts
  - Up to 1 µm shift in X and Y
  - Evaluate error in measured shift







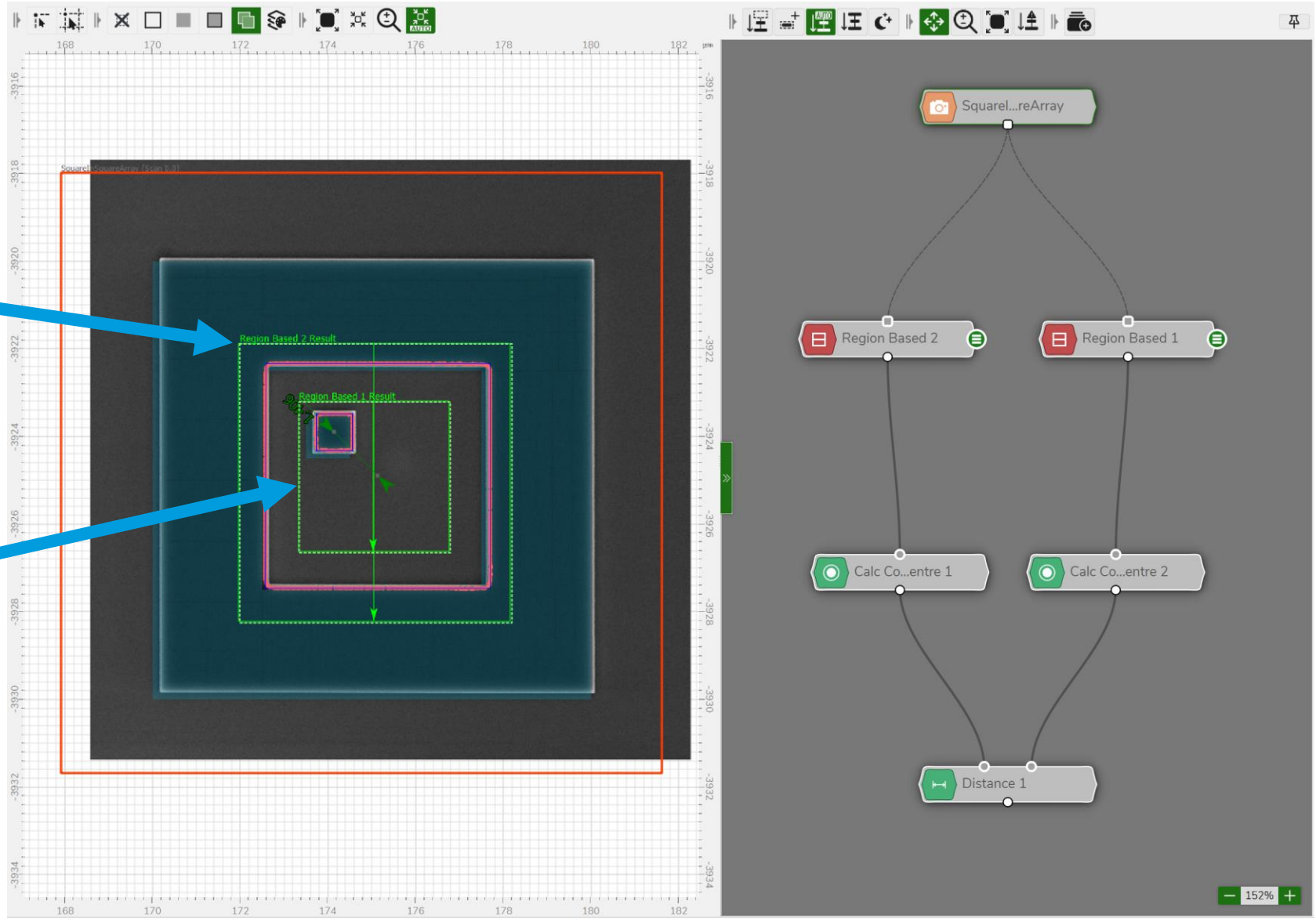


Test Pattern that has defined “placement error”

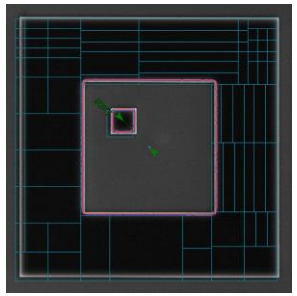
Placement Analysis

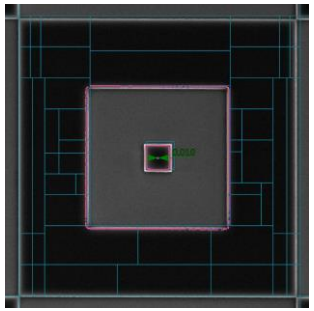
Region 1
Outside Box

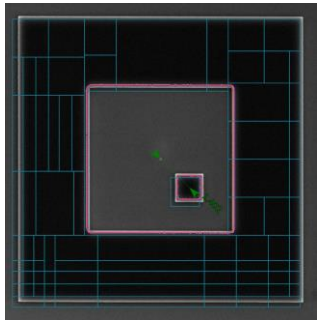
Region 2
Inside Box

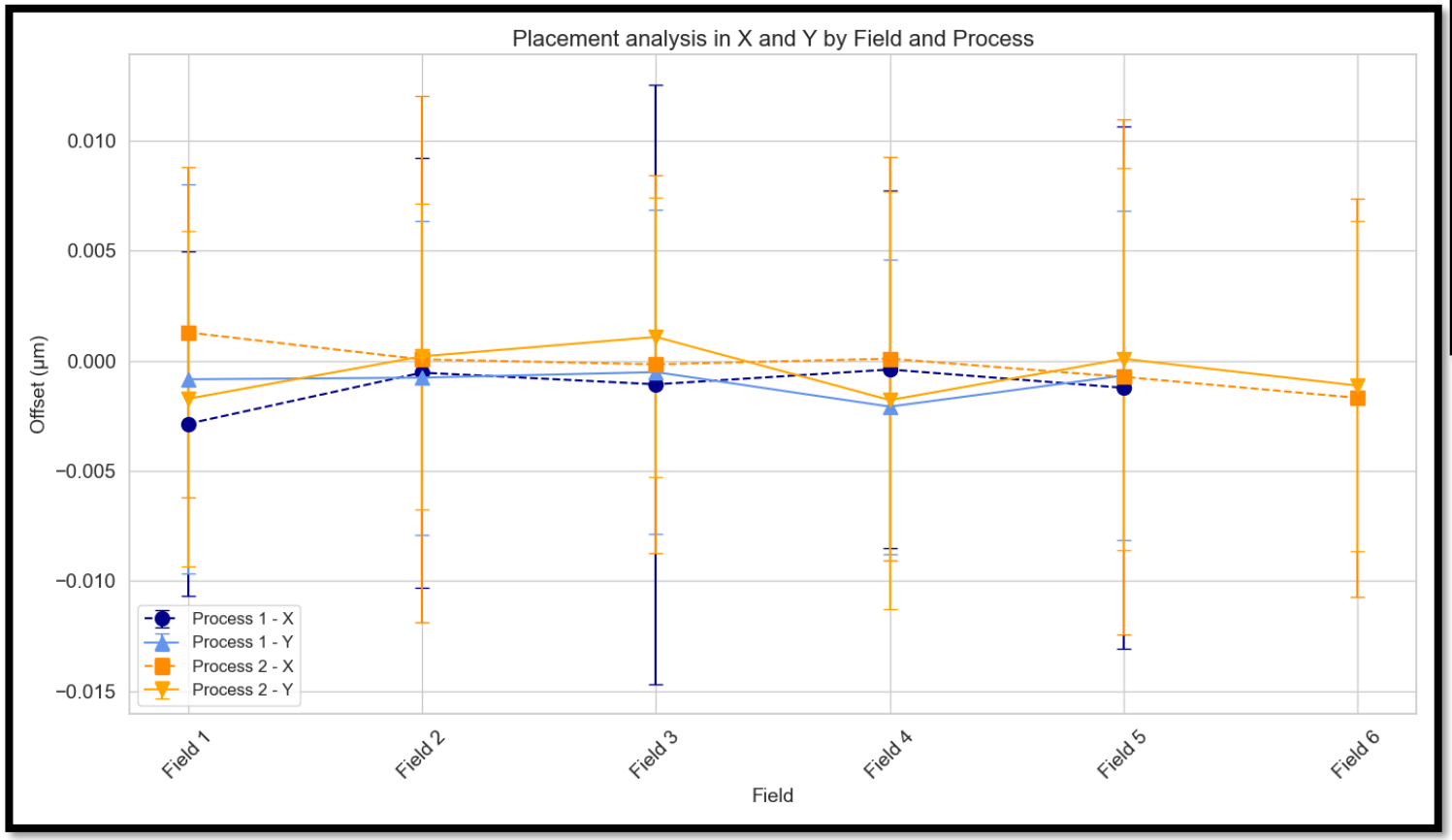


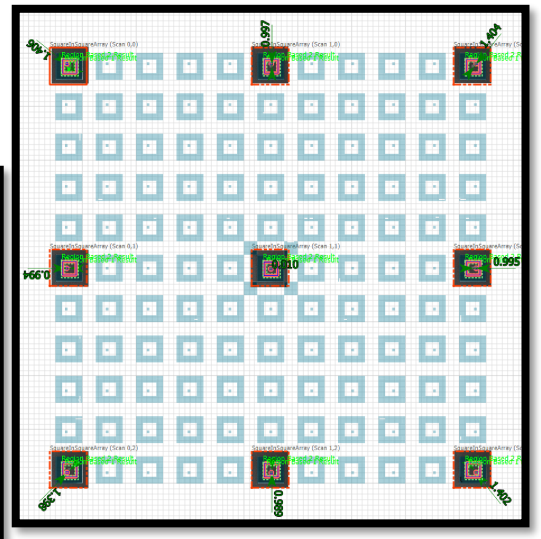
Placement Analysis











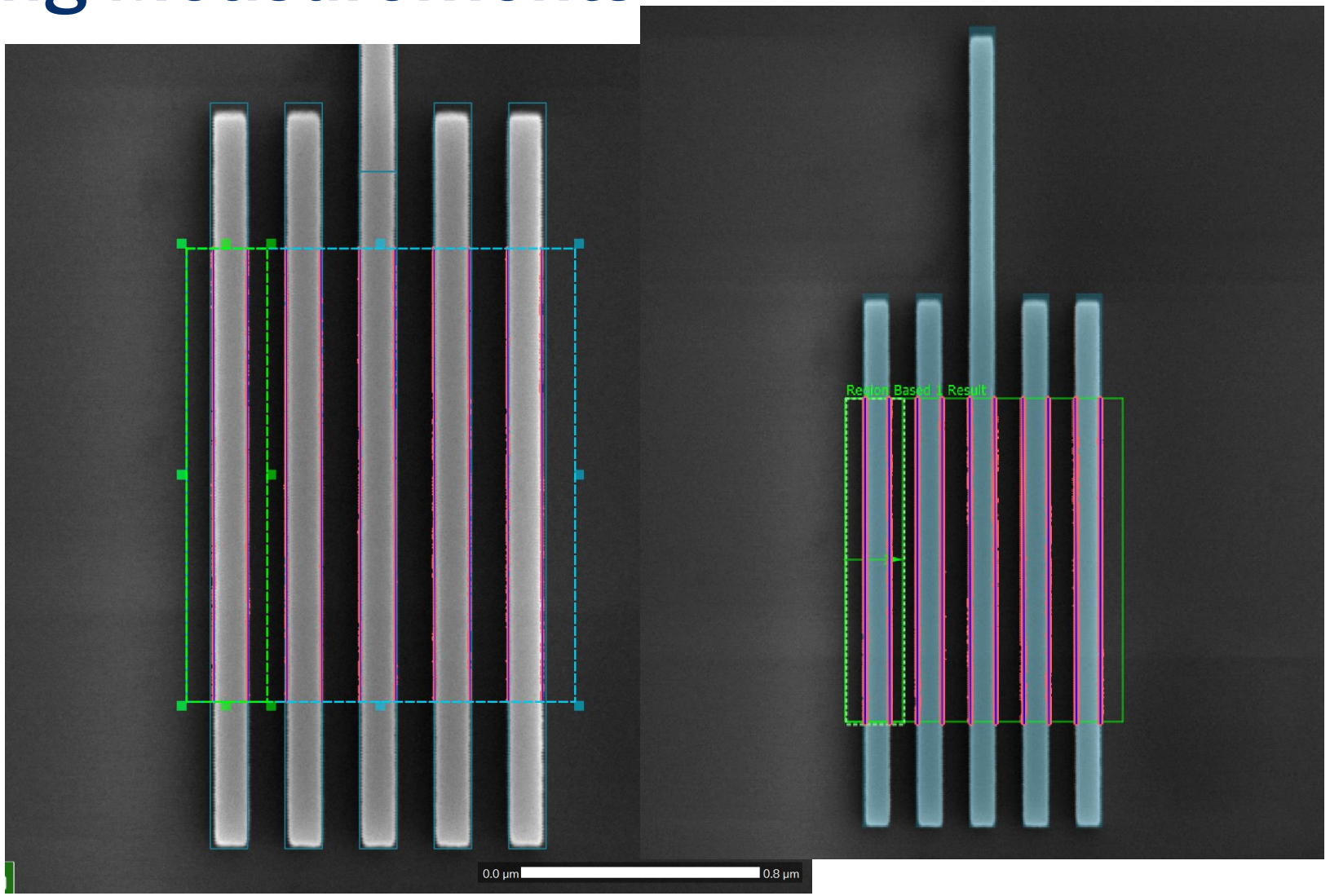
nm scale measured “error” relative to defined alignment offset

Application Examples

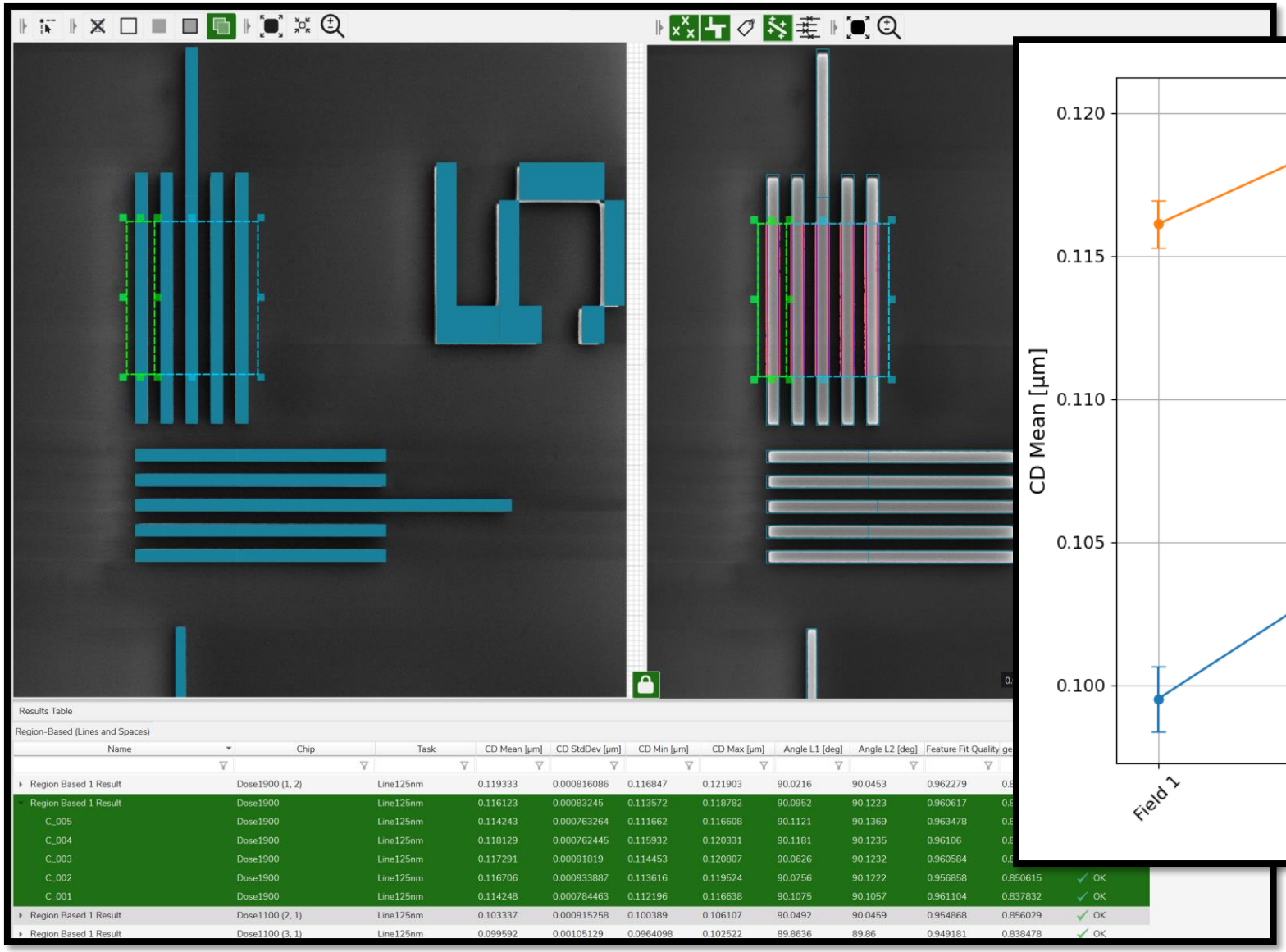
- Process Calibration
- Overlay Measurement
- **Line / Space or Grating Measurement**
- Device CD - Transistor Channel Length
- Contour Extraction – Shape fidelity / Blur extraction
- Complex Pattern – Meta Lens

Line/Space or Grating Measurements

- Line and grating analysis
  - Match single line
  - Find similar
  - Calculate CD and pitch
- Evaluate:
  - Process conditions
  - Uniformity across wafer



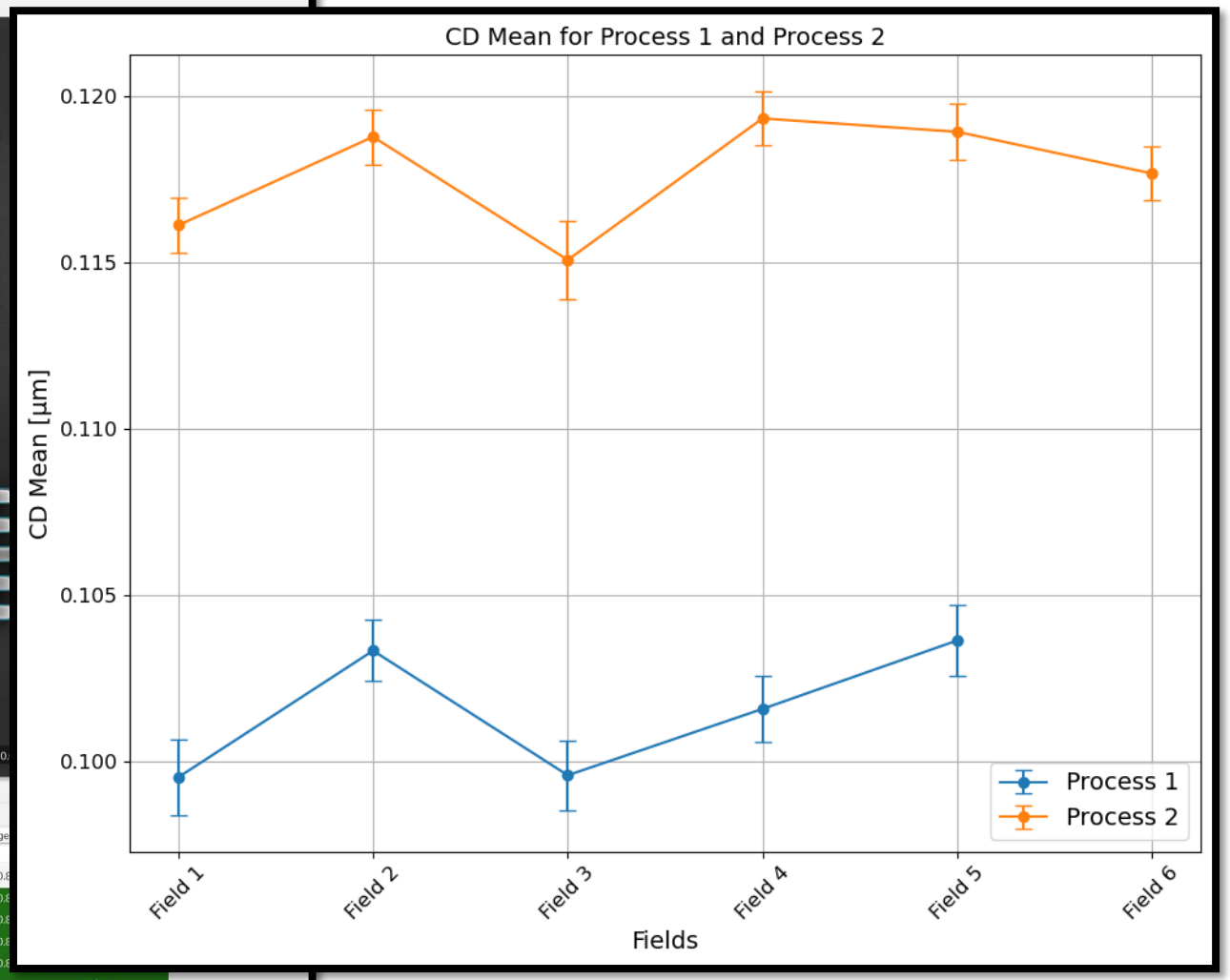
Line/Space or Grating Measurements



Results Table

Region-Based (Lines and Spaces)

Name	Chip	Task	CD Mean [µm]	CD StdDev [µm]	CD Min [µm]	CD Max [µm]	Angle L1 [deg]	Angle L2 [deg]	Feature Fit Quality		
Region Based 1 Result	Dose1900 (1, 2)	Line125nm	0.119333	0.000816086	0.116847	0.121903	90.0216	90.0453	0.962279	0.8	
Region Based 1 Result	Dose1900	Line125nm	0.116123	0.00083245	0.113572	0.118782	90.0952	90.1223	0.960617	0.8	
C_005	Dose1900	Line125nm	0.114243	0.000763264	0.111662	0.116608	90.1121	90.1369	0.963478	0.8	
C_004	Dose1900	Line125nm	0.118129	0.000762445	0.115932	0.120331	90.1181	90.1235	0.96106	0.8	
C_003	Dose1900	Line125nm	0.117291	0.00091819	0.114453	0.120807	90.0626	90.1232	0.960584	0.8	
C_002	Dose1900	Line125nm	0.116706	0.000933887	0.113616	0.119524	90.0756	90.1222	0.956858	0.850615	OK
C_001	Dose1900	Line125nm	0.114248	0.000784463	0.112196	0.116638	90.1075	90.1057	0.961104	0.837832	OK
Region Based 1 Result	Dose1100 (2, 1)	Line125nm	0.103337	0.000915258	0.100389	0.106107	90.0492	90.0459	0.954868	0.856029	OK
Region Based 1 Result	Dose1100 (3, 1)	Line125nm	0.099592	0.00105129	0.0964098	0.102522	89.8636	89.86	0.949181	0.838478	OK



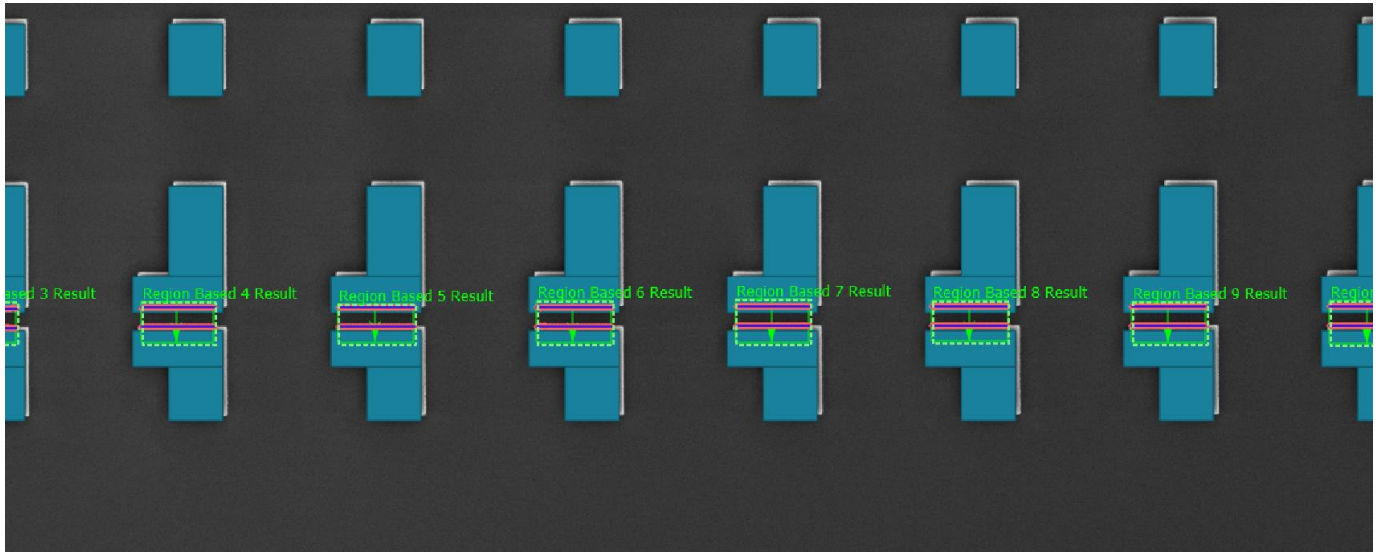
125nm Layout CD

Application Examples

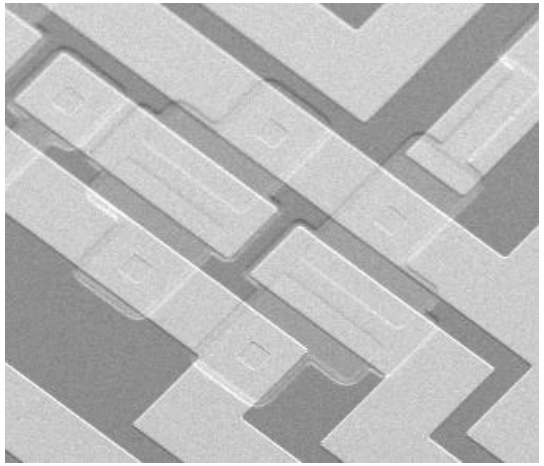
- Process Calibration
- Overlay Measurement
- Line / Space or Grating Measurement
- **Device CD - Transistor Channel Length**
- Contour Extraction – Shape fidelity / Blur extraction
- Complex Pattern – Meta Lens

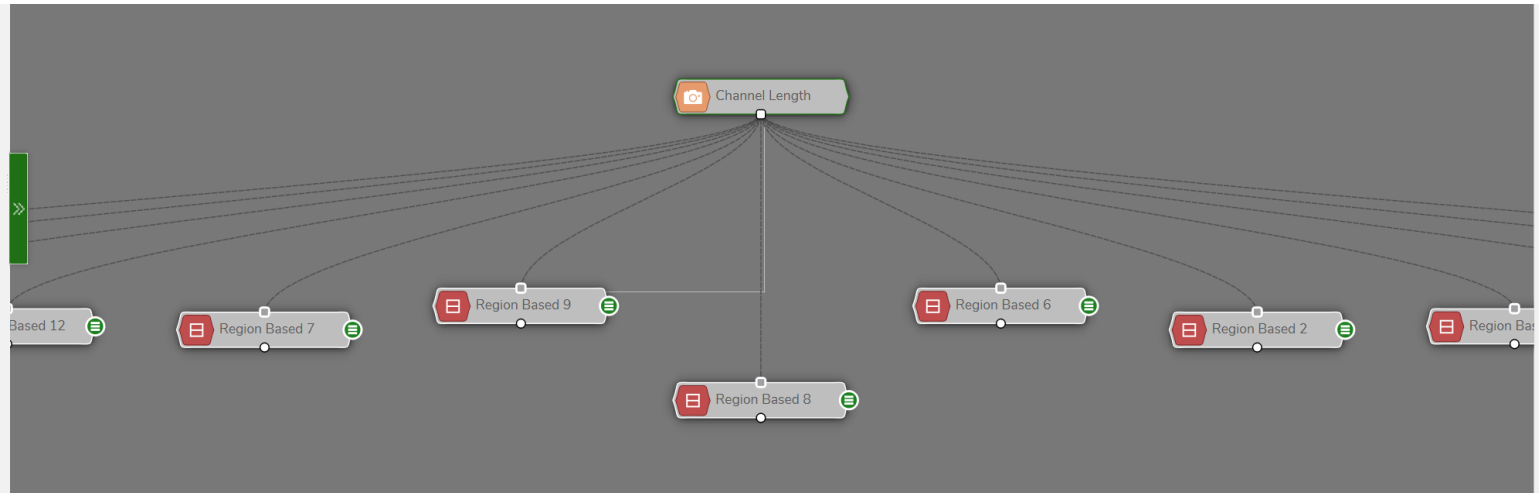
Device CD Measurement

- Transistor channel length
  - Crucial for device characteristics
  - Correlated to specific device
  - Several measurements per scan
  - CD measurement: mean, min, max, std dev.
  - Includes angle of both edges

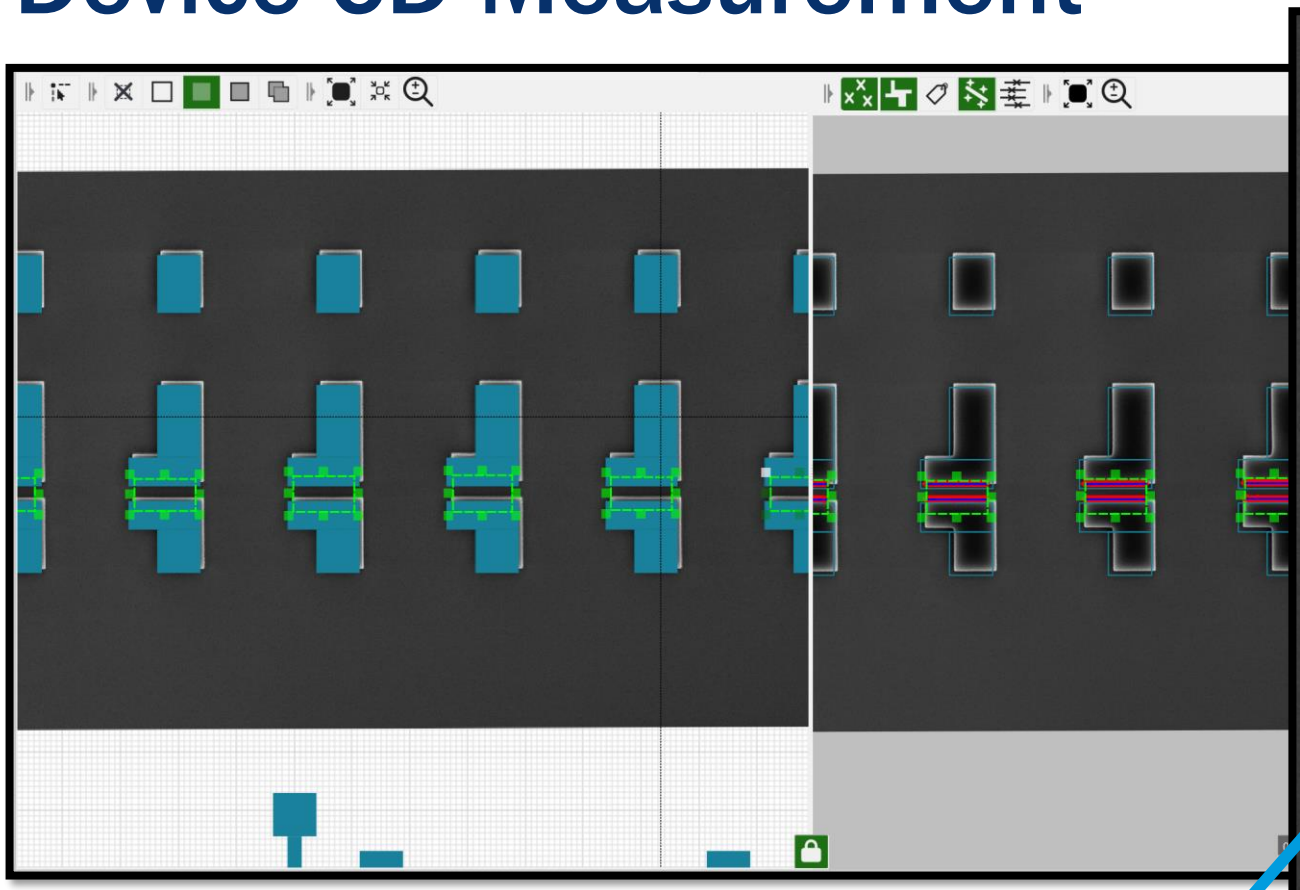


- Evaluate:
  - Process conditions
  - Uniformity across wafer
  - Link to device performance



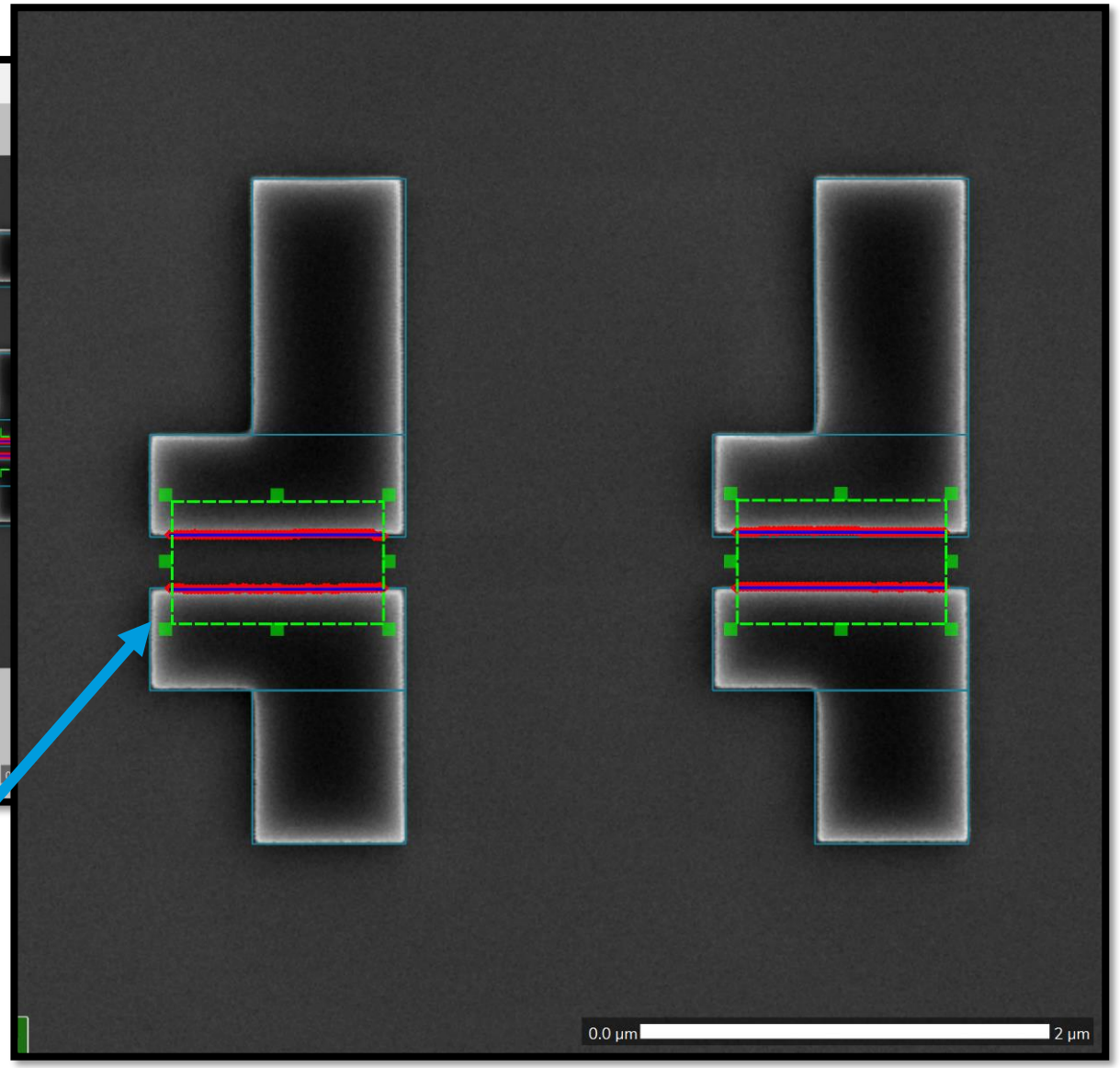


Device CD Measurement

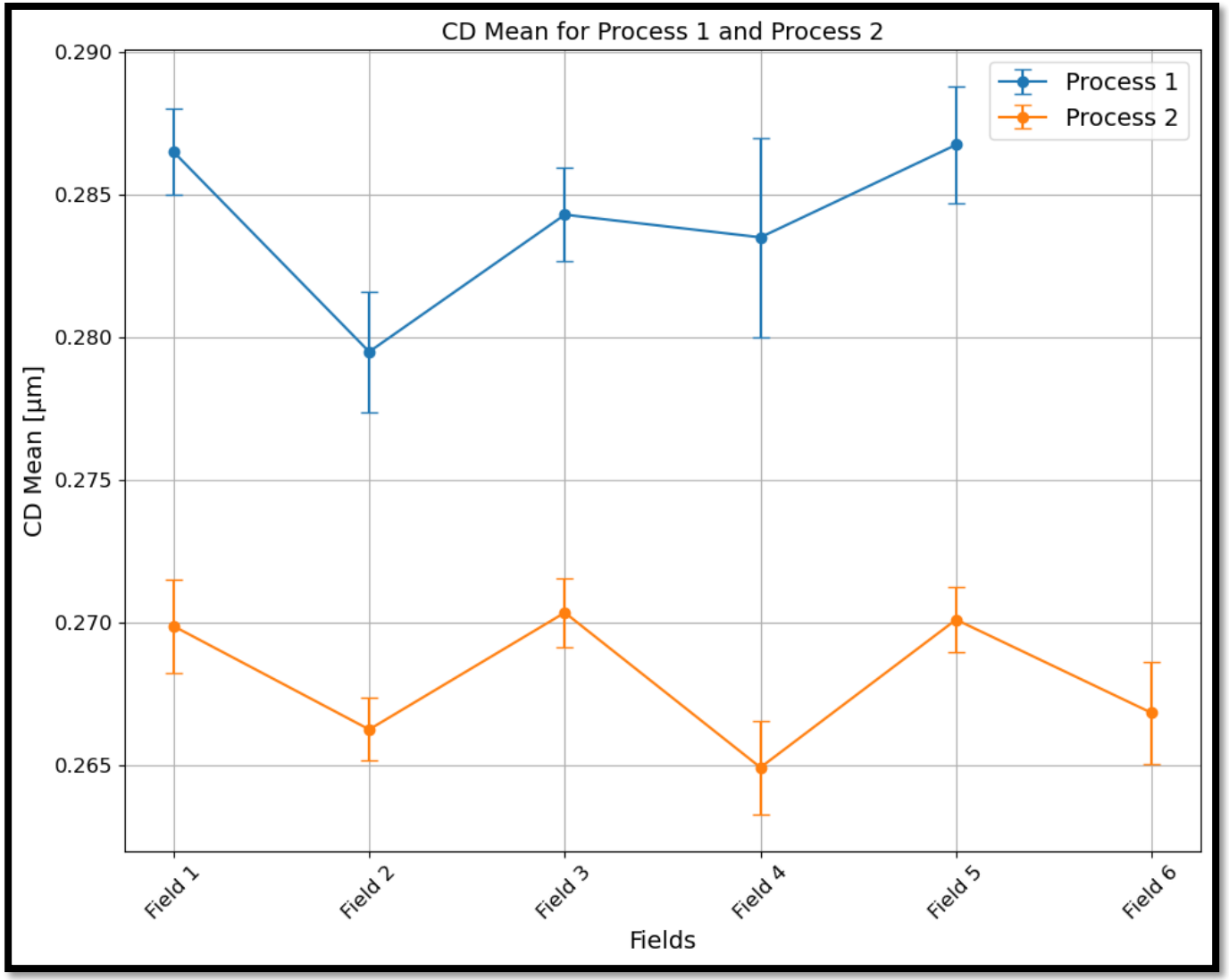


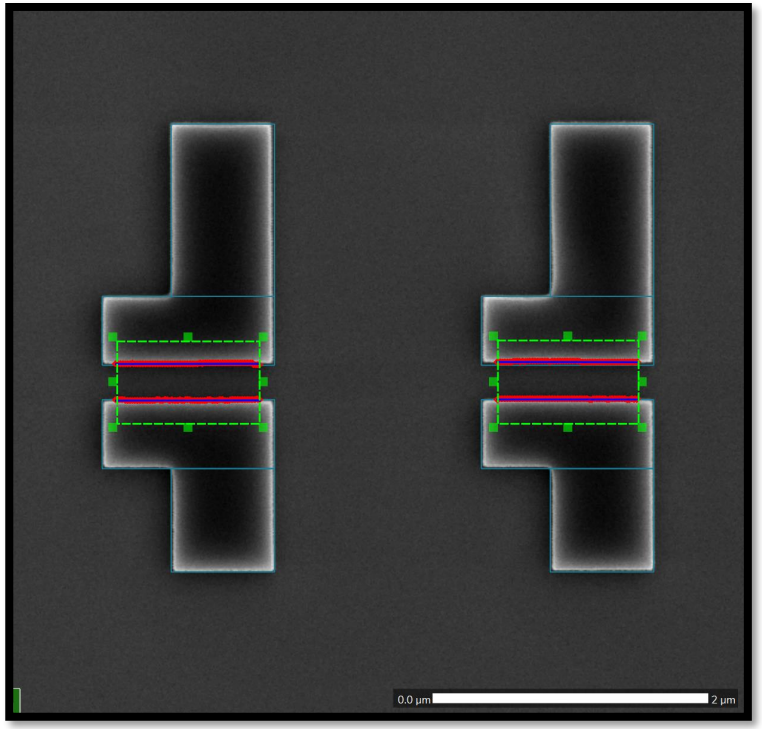
Pattern Registration

Measurement



Device CD Measurement





250nm Layout CD

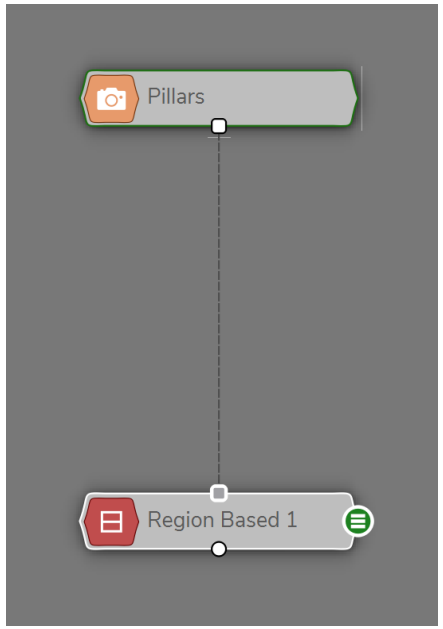
Application Examples

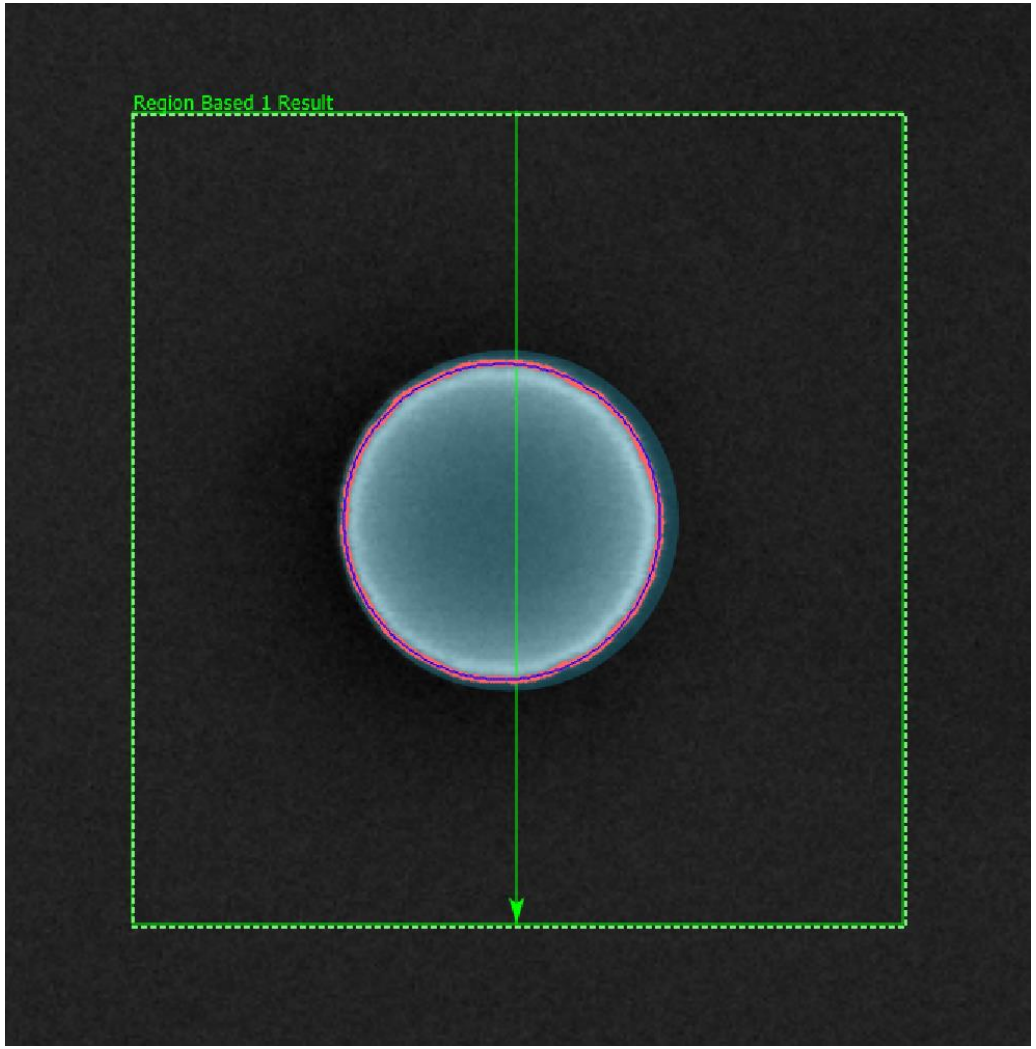
- Process Calibration
- Overlay Measurement
- Line / Space or Grating Measurement
- Device CD - Transistor Channel Length
- **Contour Extraction – Shape fidelity / Blur extraction**
- Complex Pattern – Meta Lens

Contours and PV bands

- Shape fidelity and process variation
  - Acquire Image
  - Detect shapes
  - Fields with different conditions/ locations
  - Collect and export contours
  - Combine to PV band (process variation)

- Evaluate:
  - Process conditions
  - Uniformity across wafer





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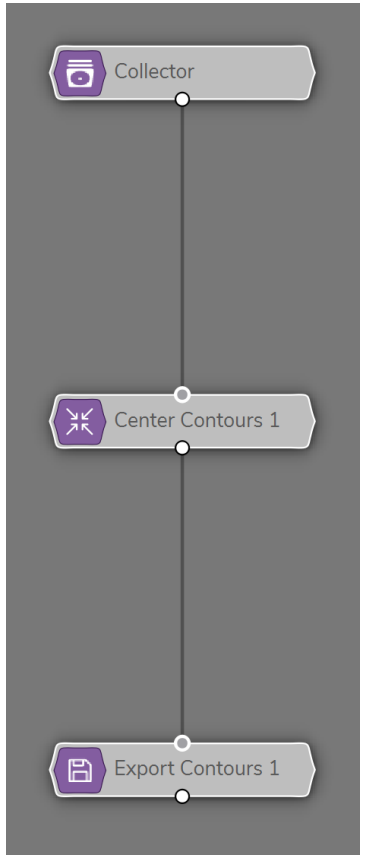
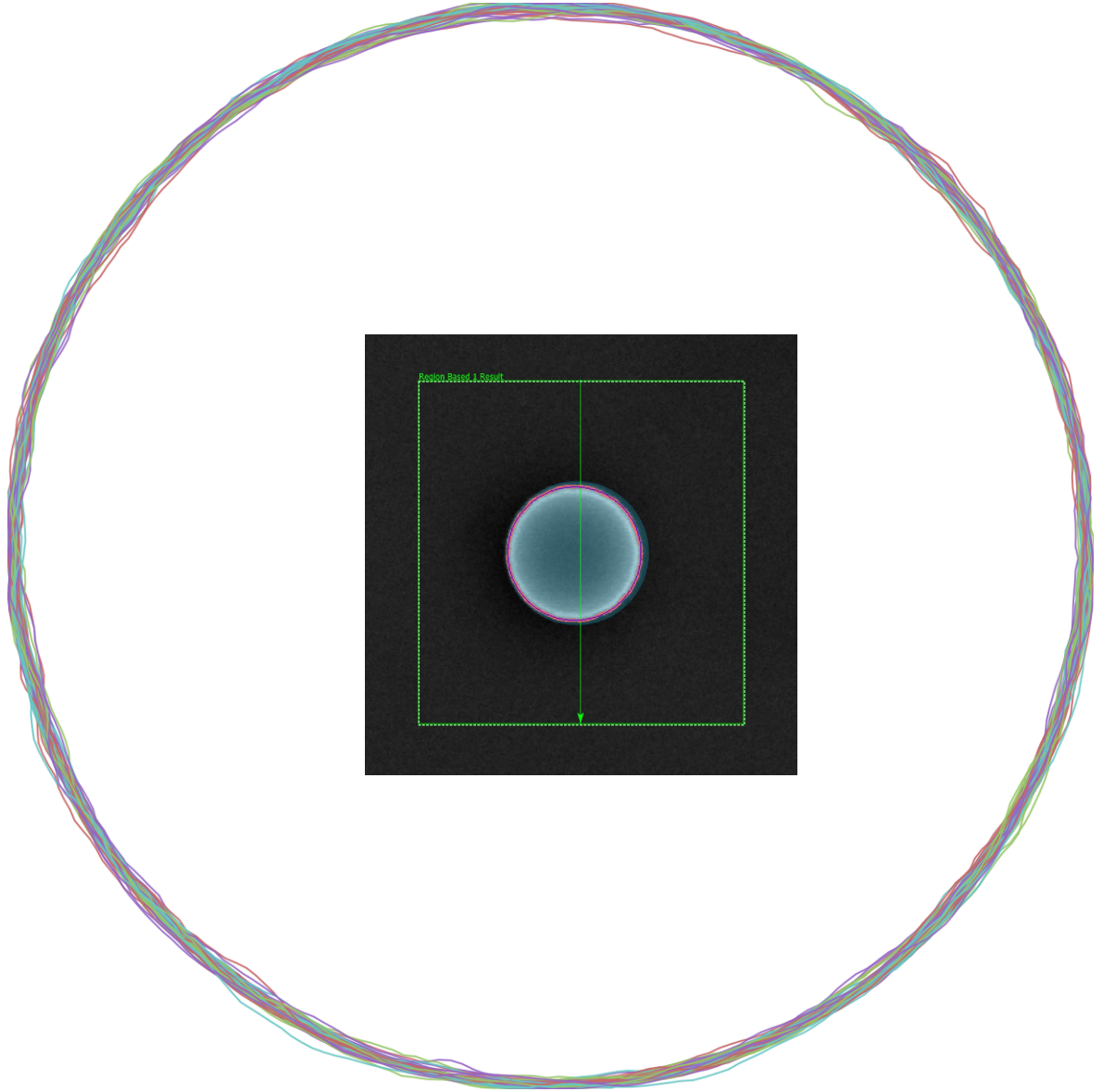
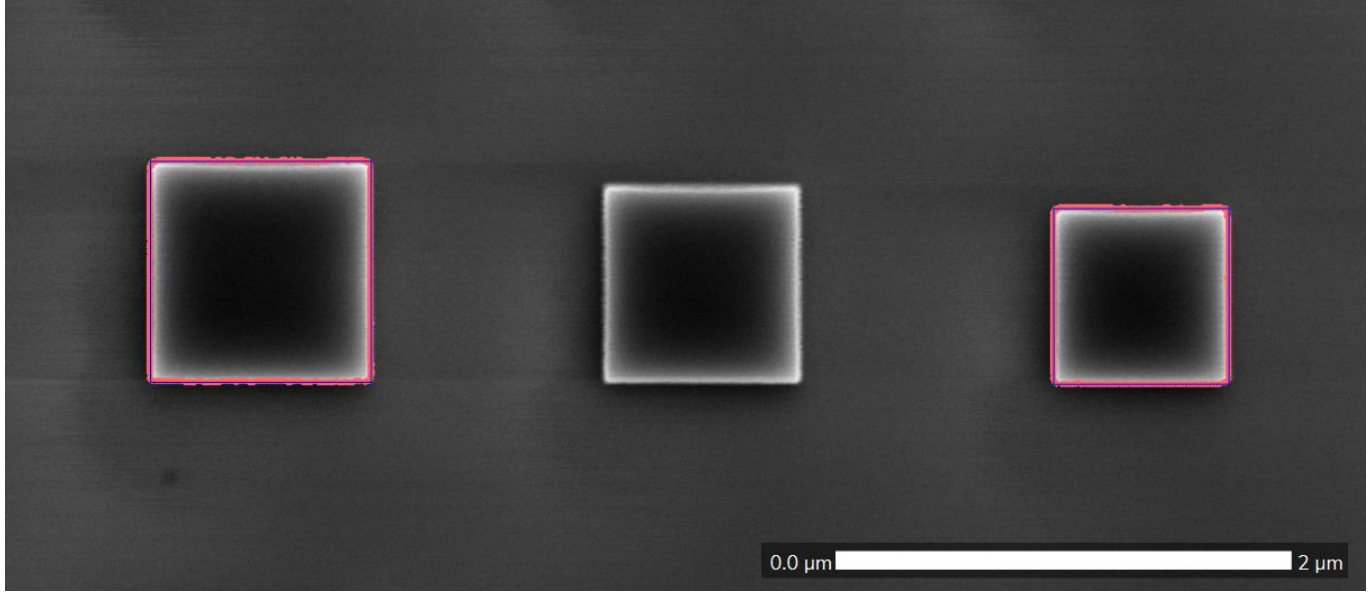
  - Process conditions
  - Uniformity across wafer

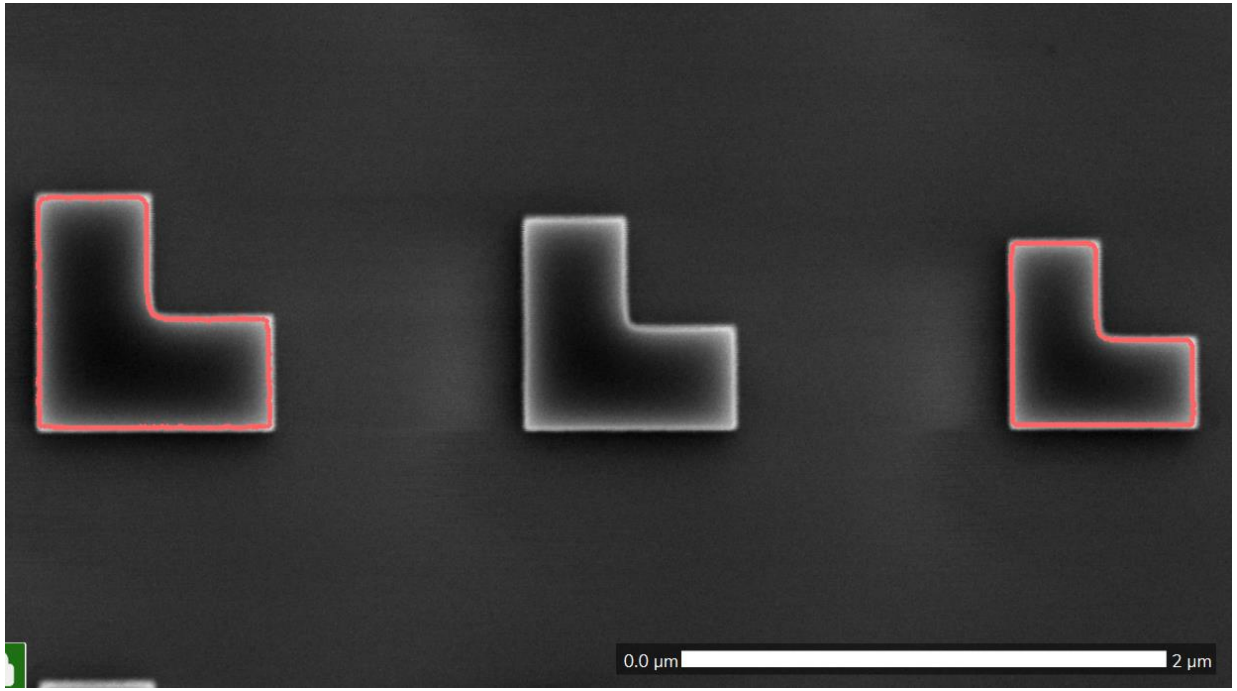


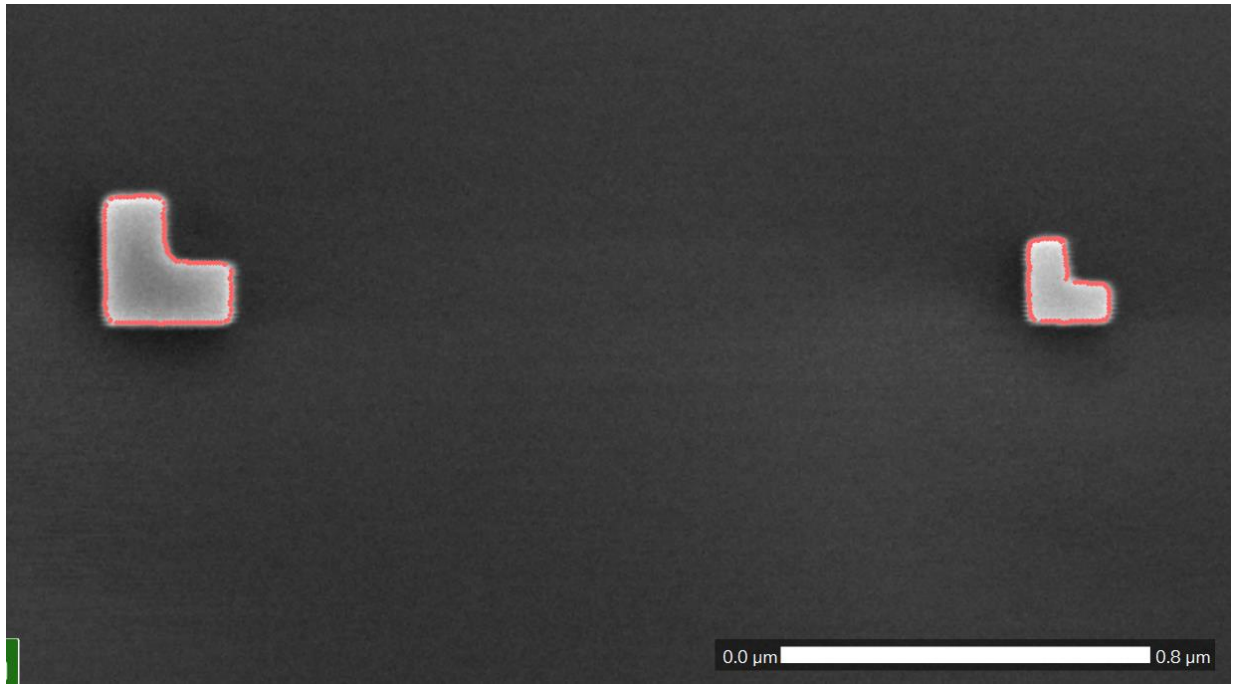


Corner Rounding

- Shape fidelity and process blur
  - Test pattern for outer/ inner corners
  - Fitting of corner rounding
  - Measure radius
  - Export contours for comparison



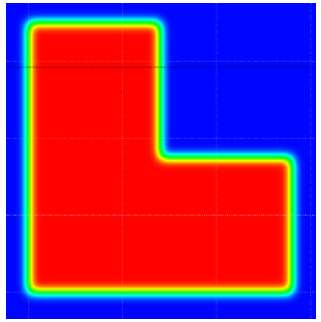




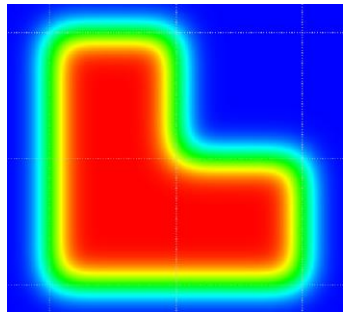
Corner Rounding

- Shape fidelity and process blur
  - Test pattern with elbows that have outer/ inner corners
  - Fitting of corner rounding
  - Measure radius
  - Export contours for comparison
- ProSEM measurements (for now)

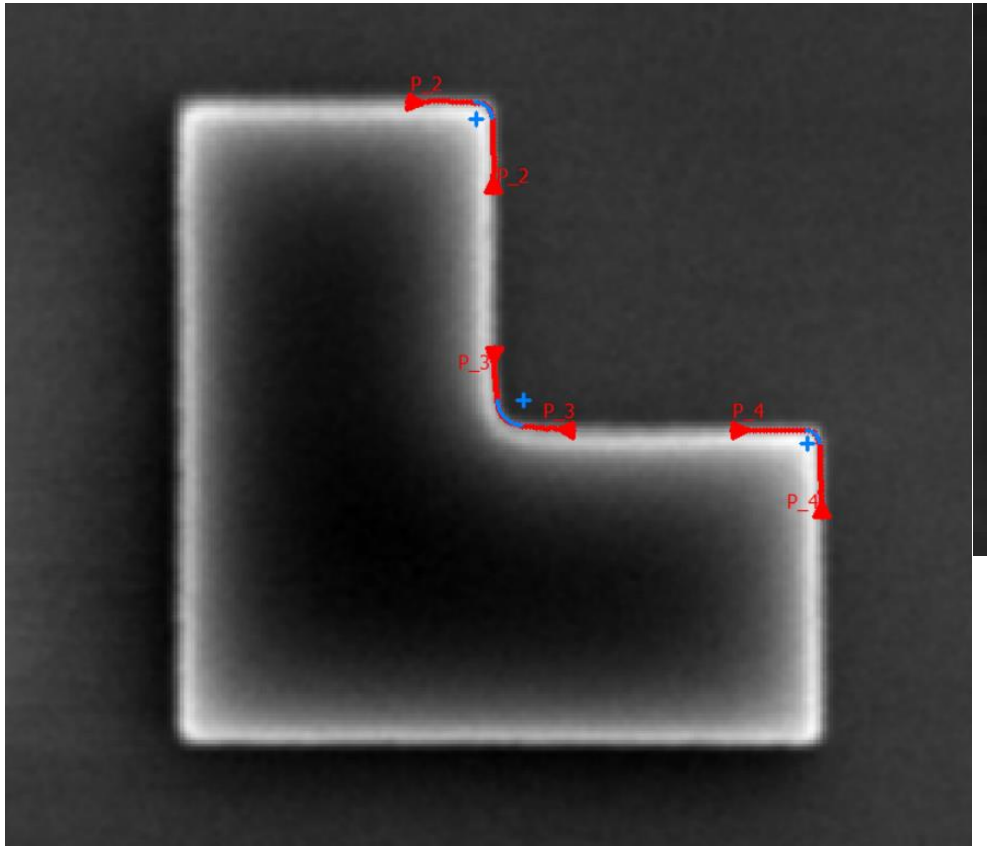
30 nm Blur for comparison



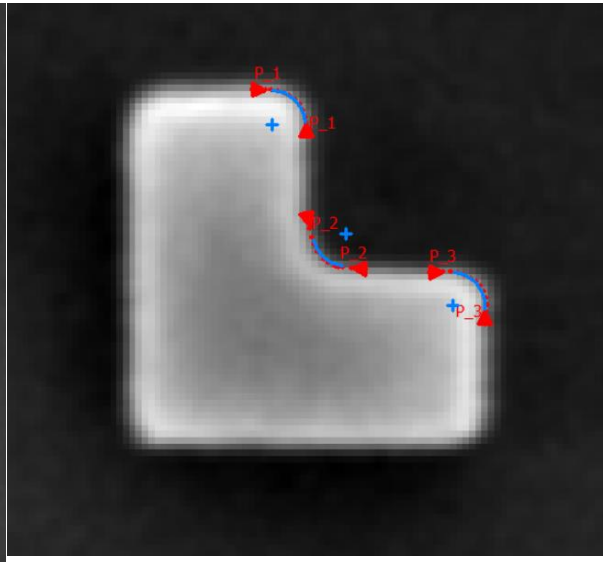
Large



Small



Large elbow:
26 nm, 19 nm outer
40 nm inner



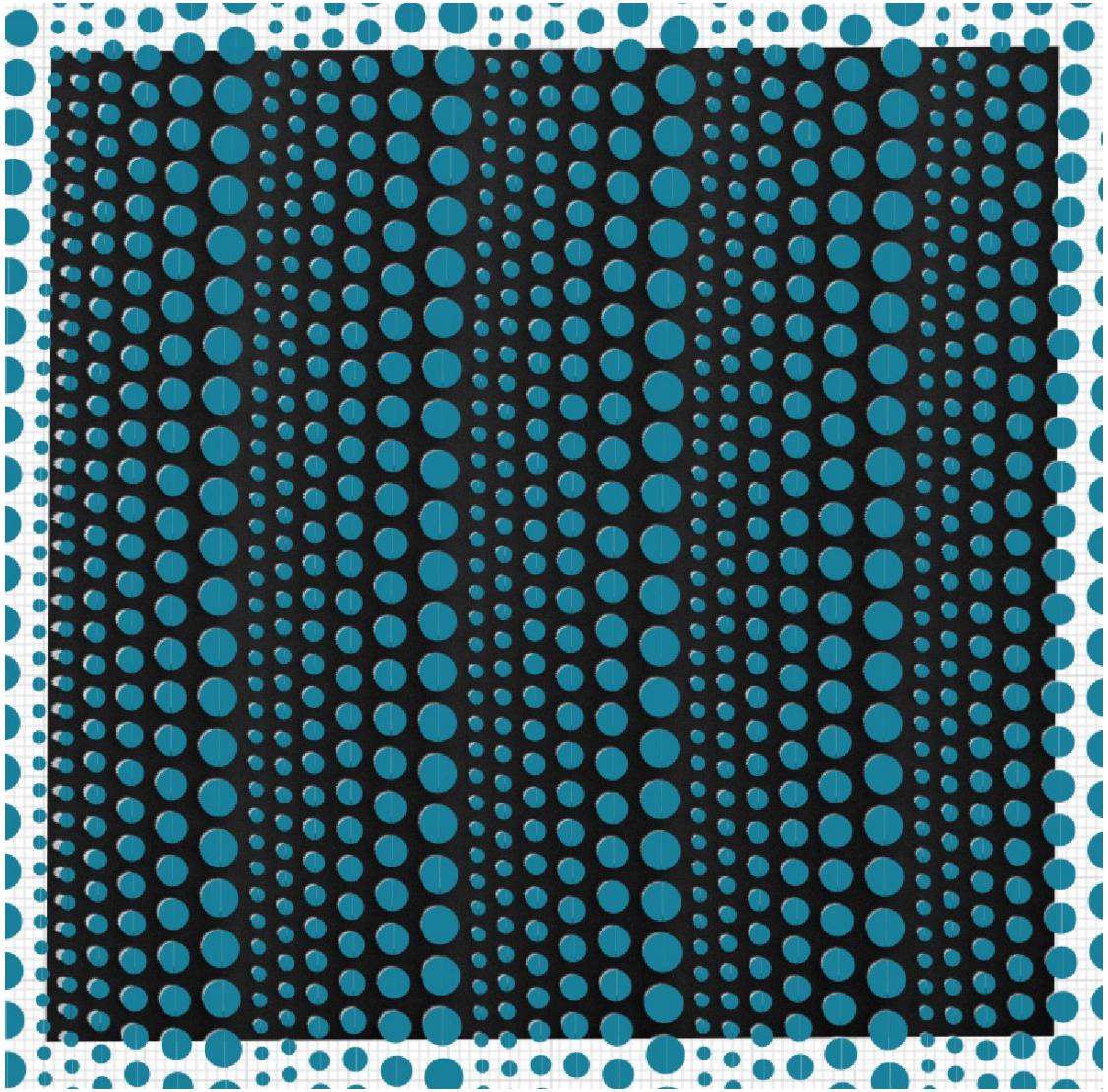
Small elbow:
27 nm, 26 nm outer
27 nm inner

Application Examples

- Process Calibration
- Overlay Measurement
- Line / Space or Grating Measurement
- Device CD - Transistor Channel Length
- Contour Extraction – Shape fidelity / Blur extraction
- **Complex Pattern – Meta Lens**

Meta Lens – Complex pattern

- Image-to-layout registration
  - Good alignment allows for more advanced studies
- Layout comparison for shape analysis
  - Compare to layout (target design)
  - Correlation of shapes vs. measurements
  - Look to extract bias for features vs. size
  - New approach for metrology required



Acknowledgements

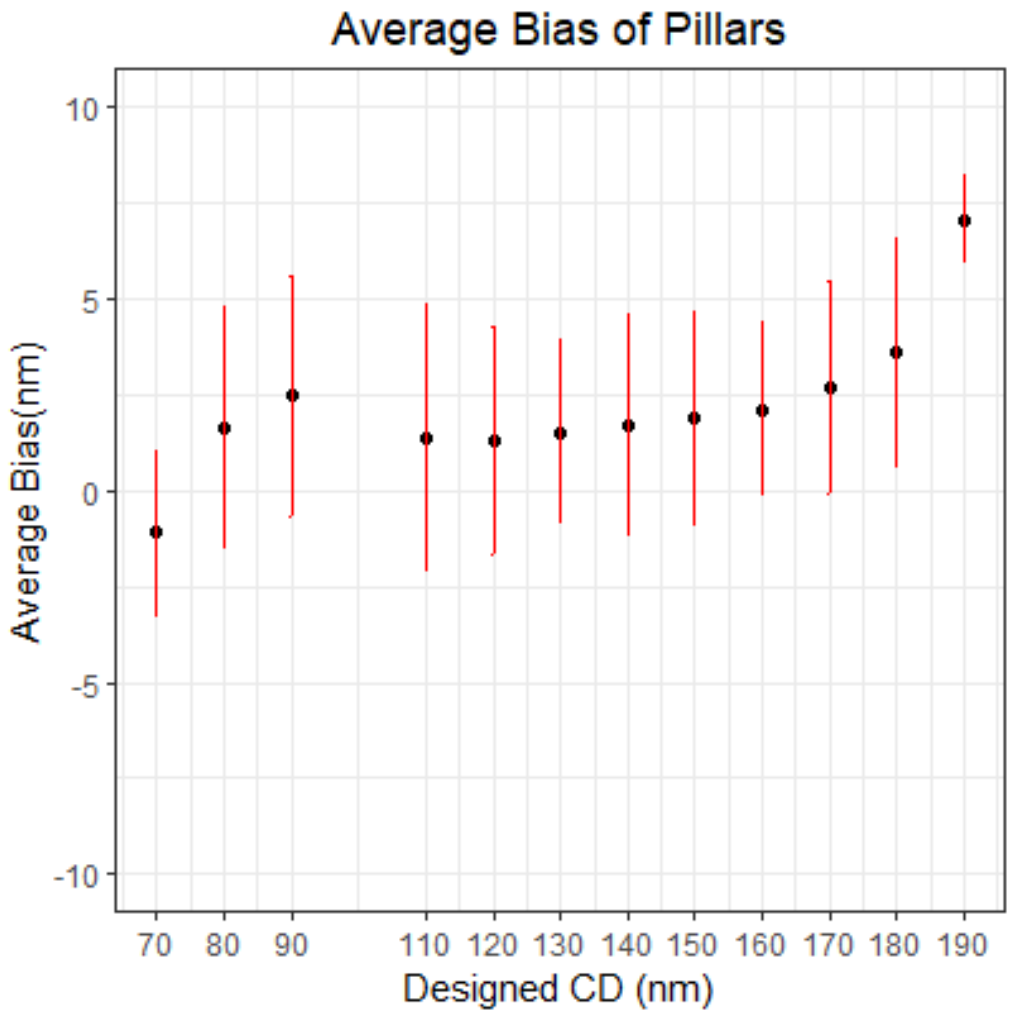
- Talk on Friday after lunch:
  - Session 8A

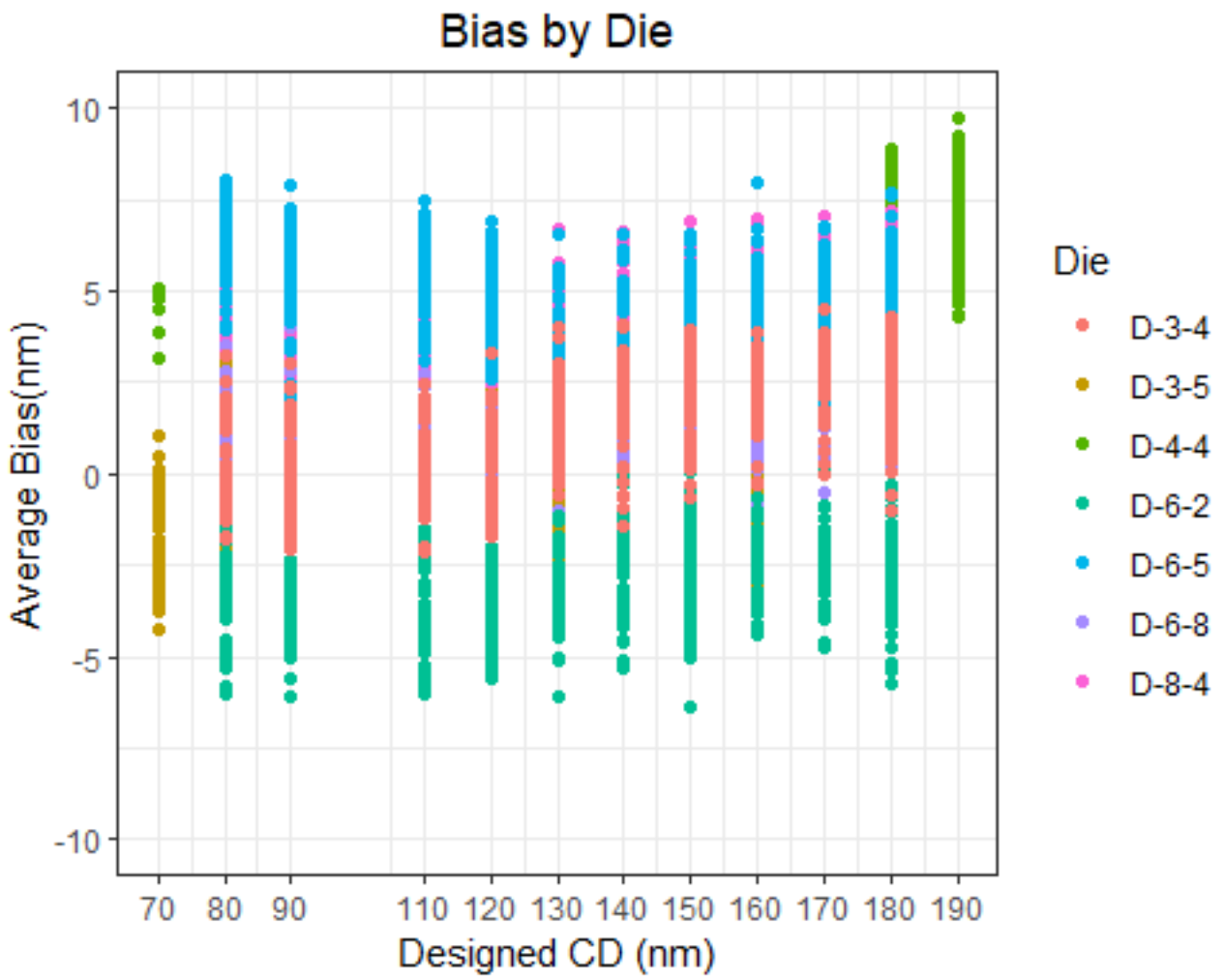
- Thanks to PSU team
  - Michael Labella
  - Bangzhi Liu

- Thanks to GeniSys team, especially:
  - Sven Bauerdick
  - Marvin Zai
  - Klaus Geib

BACKUP SLIDES

Results from wafer with “REAL” design





Designed CD put into bins by nearest 10nm 4337 Measurements across 200mm wafer