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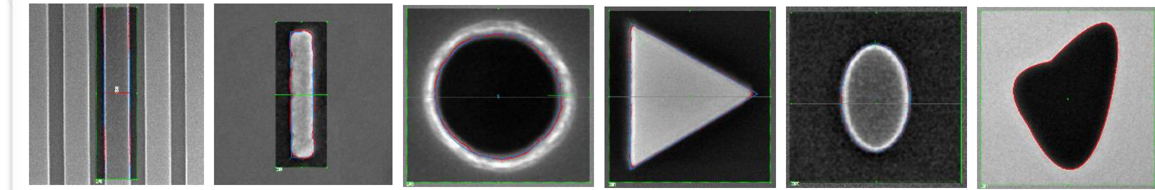
Dr. Anirudh Peyyety

ProSEM

Application Use Cases

ProSEM – easy and flexible

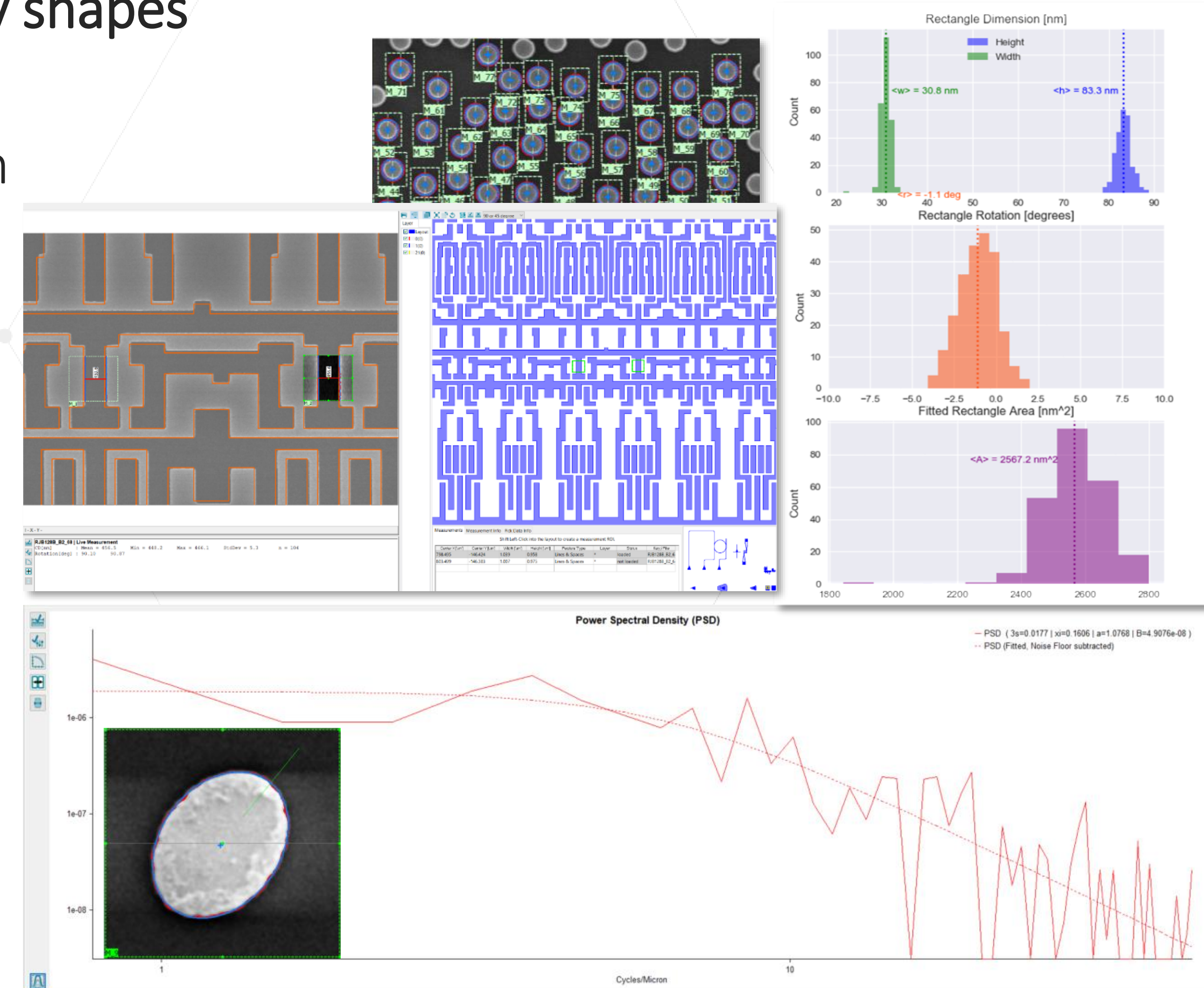
Core ProSEM features at glance:



- Seamless integration of SEM images
- Metrology on standard CMOS, complex & **arbitrary shapes**
- Robust **automatic edge detection** & **find similar**
- Quick **batch processing** and custom recipe creation
- Easy data handling and export (csv, gds)
- Python scripting support & more..

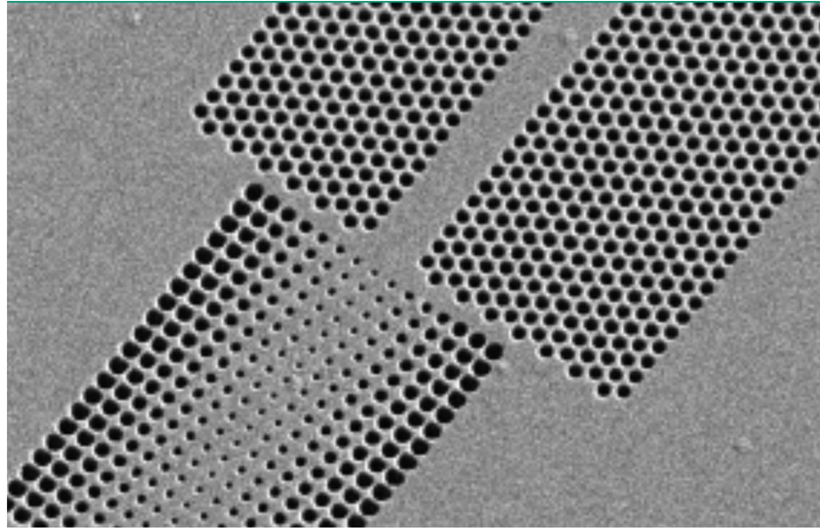
Extended ProSEM functionality:

- **Layout integration** & Metrology
- Line Edge analysis for 2D shapes
- **Find modified** shapes
- Pixel size calibration from 2D pitch
- Digital interface for SEM automation



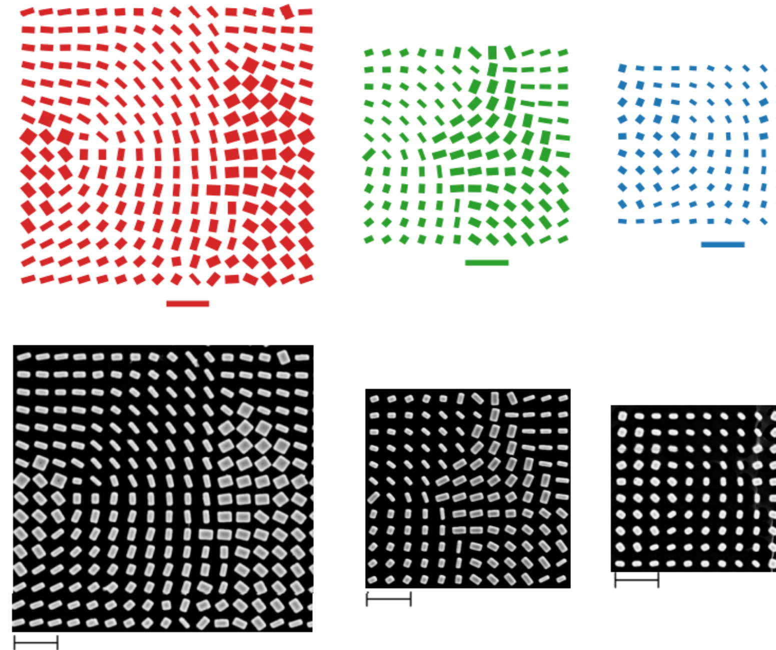
Applications

Photonic Crystals



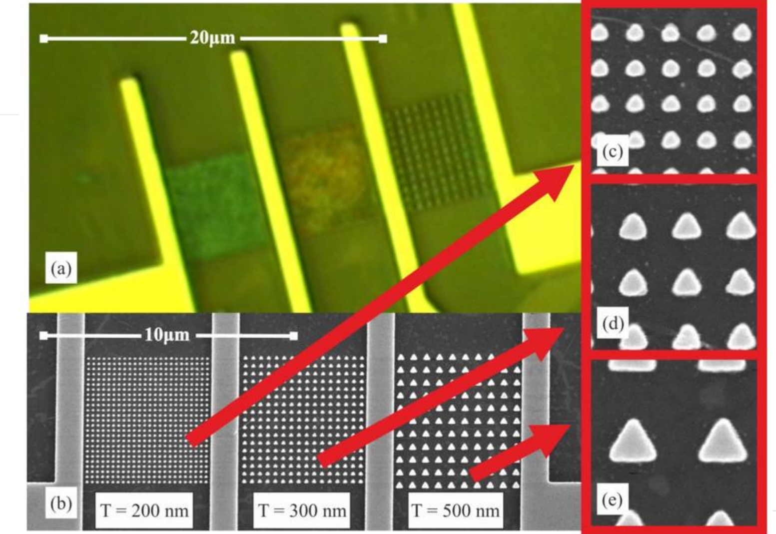
Fraunhofer IOF

Metasurfaces



L. W. Li et al., Applied Optics, 7(62), 2023

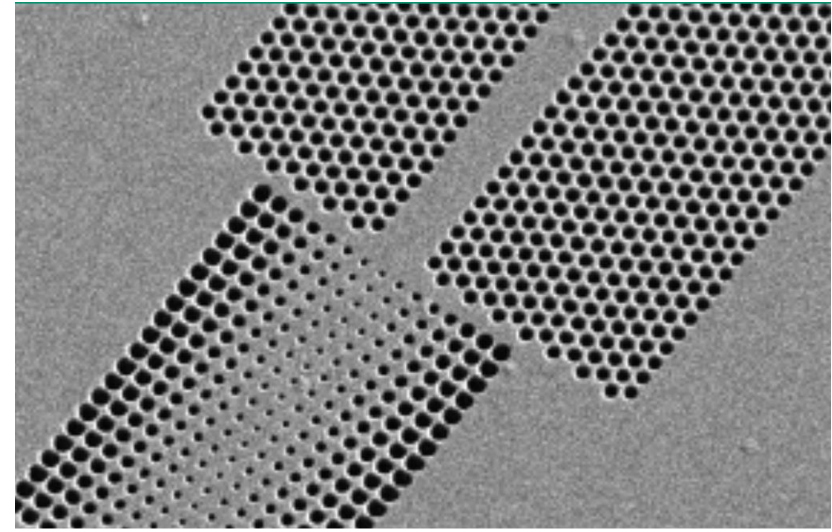
Optoelectronics



A. Guskov, Nanomaterials 12(11):1854, 2022

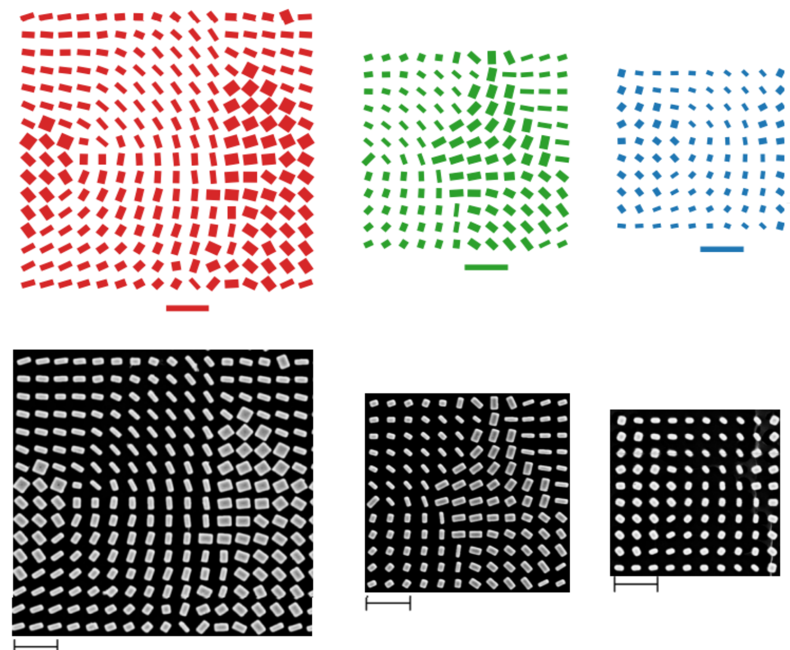
Applications

Photonic Crystals



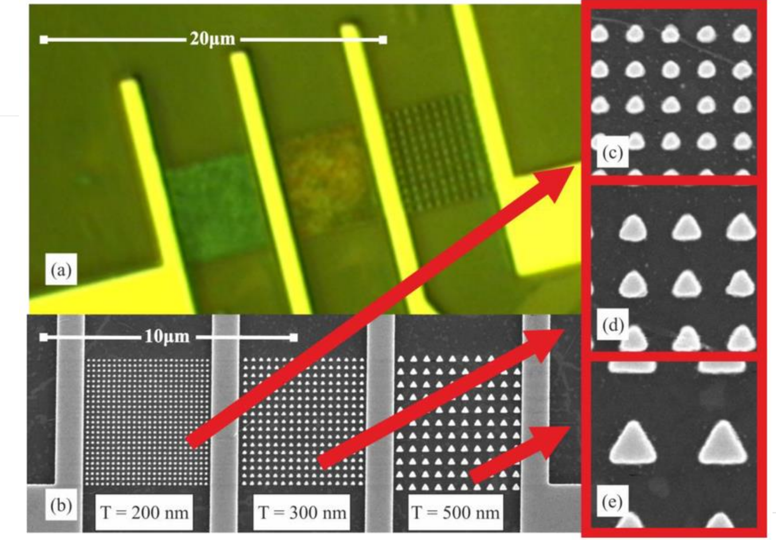
Fraunhofer IOF

Metasurfaces



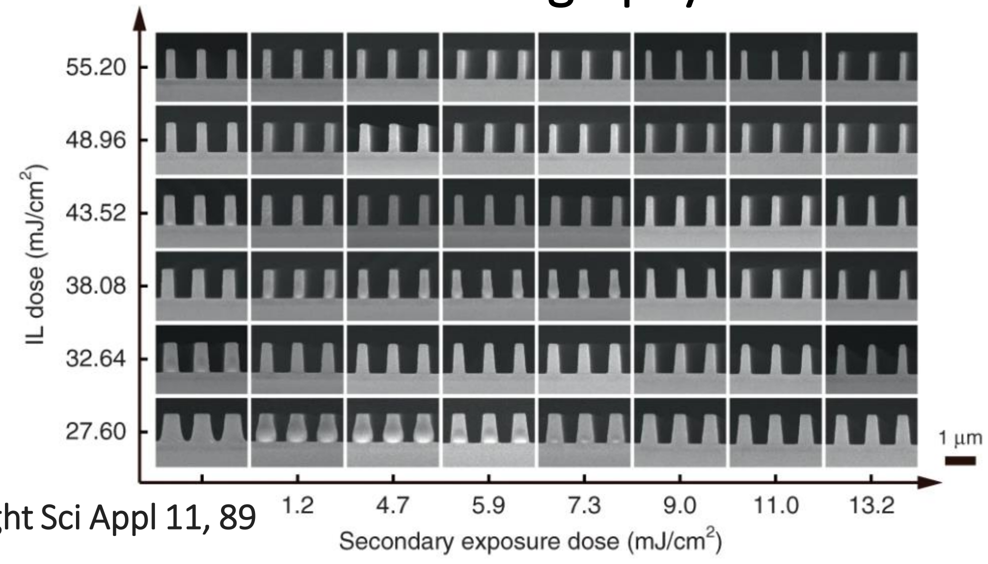
L. W. Li et al., Applied Optics, 7(62), 2023

Optoelectronics

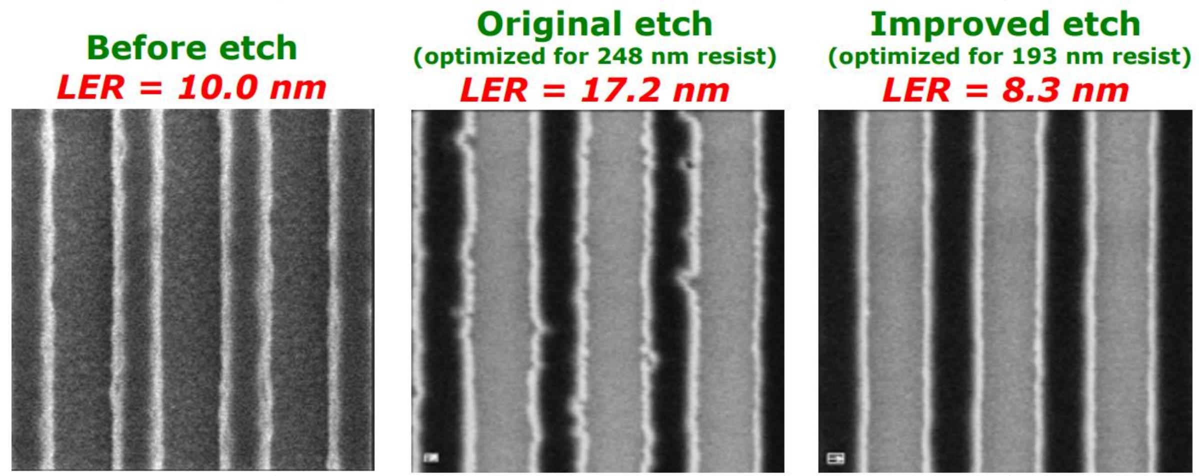


A. Guskov, Nanomaterials 12(11):1854, 2022

Nanolithography



Gan Z et al., Light Sci Appl 11, 89 (2022)



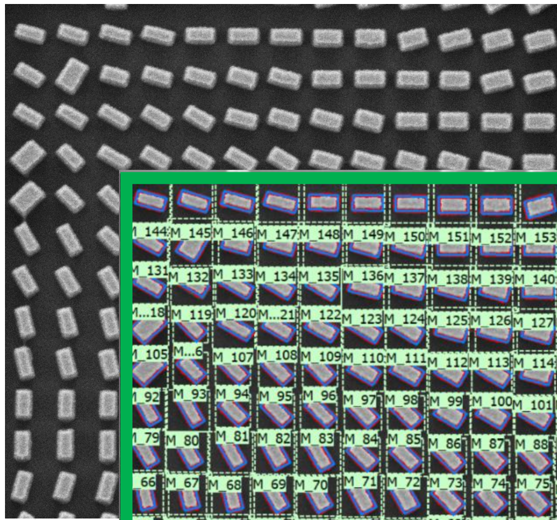
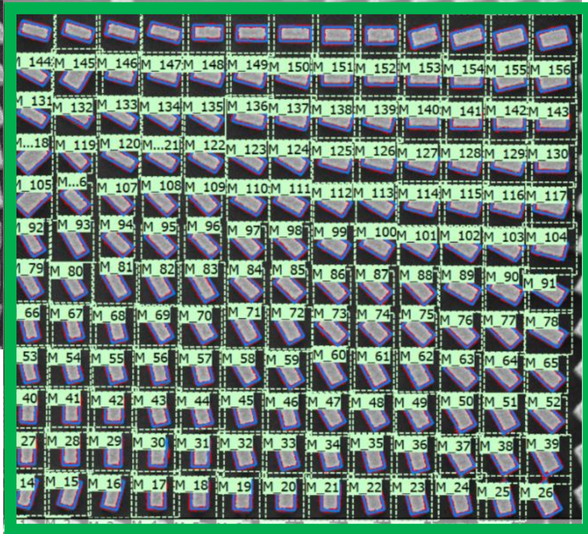
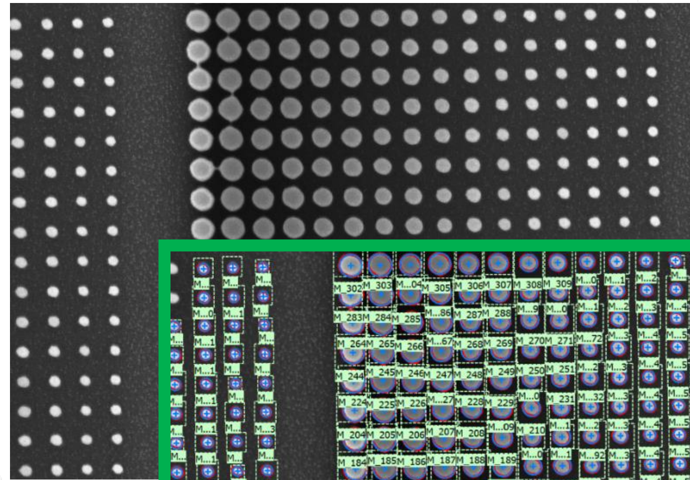
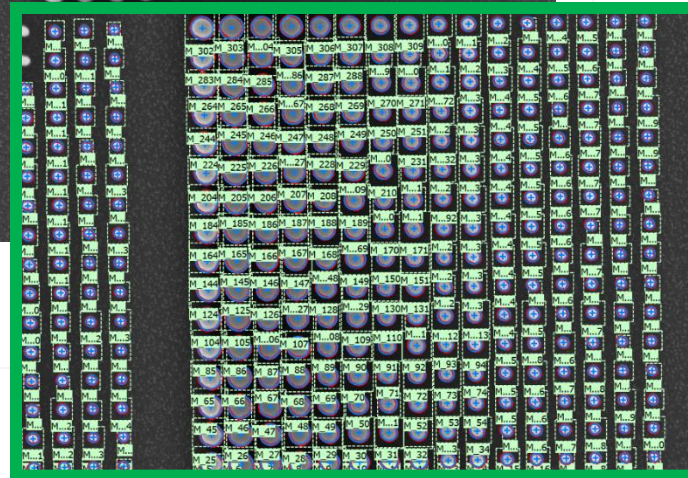
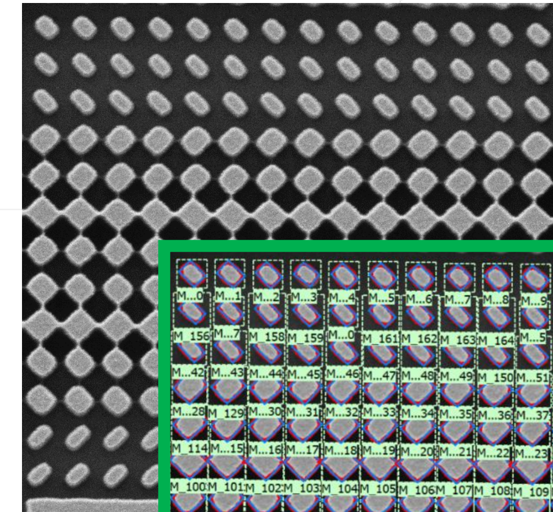
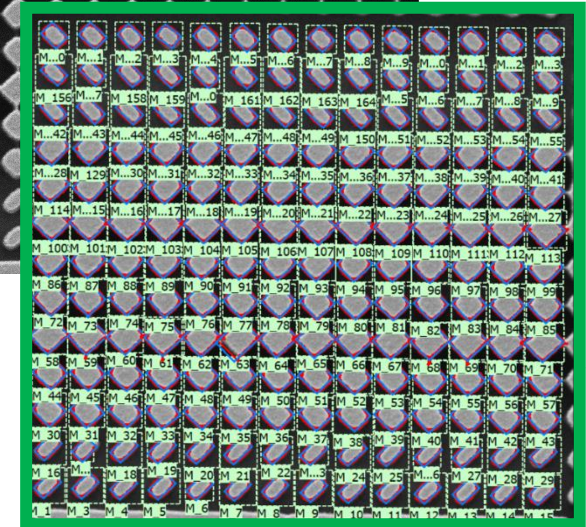
Calvin G. et al., AMD ICMI 2003

ProSEM Application Use Cases

- ❑ Nanostructure image analysis
- ❑ Corner rounding analysis
- ❑ Line Edge Roughness
- ❑ Side-wall analysis
- ❑ Layout-based metrology

Nanostructure image analysis

Nanostructure image analysis

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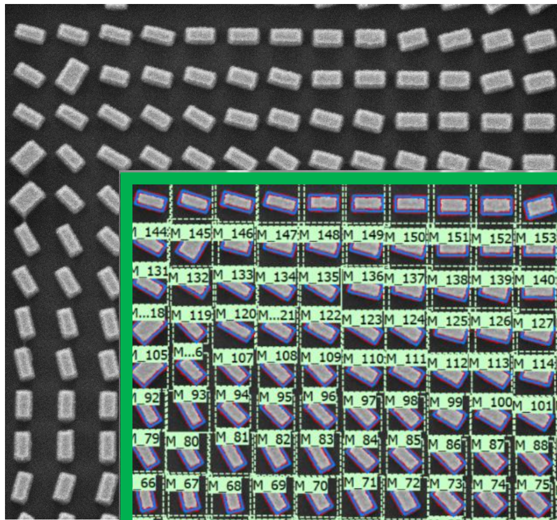
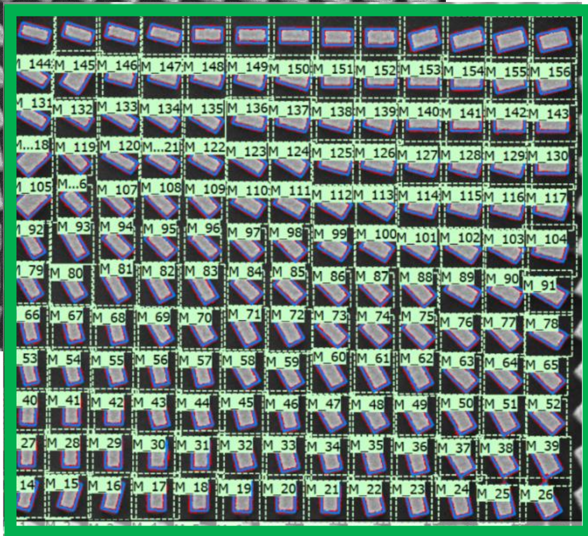
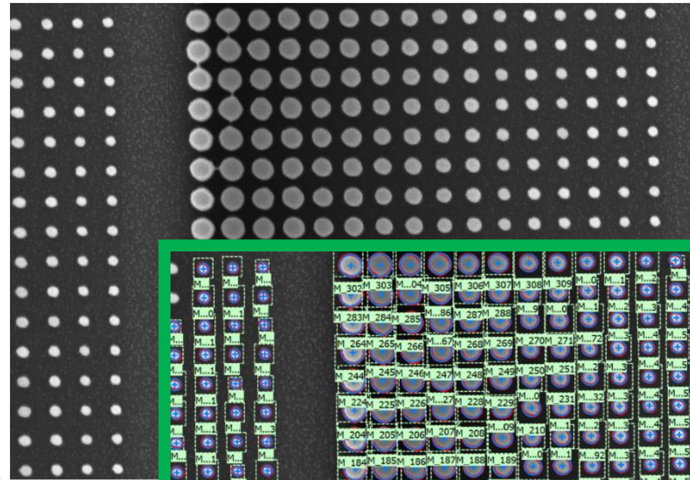
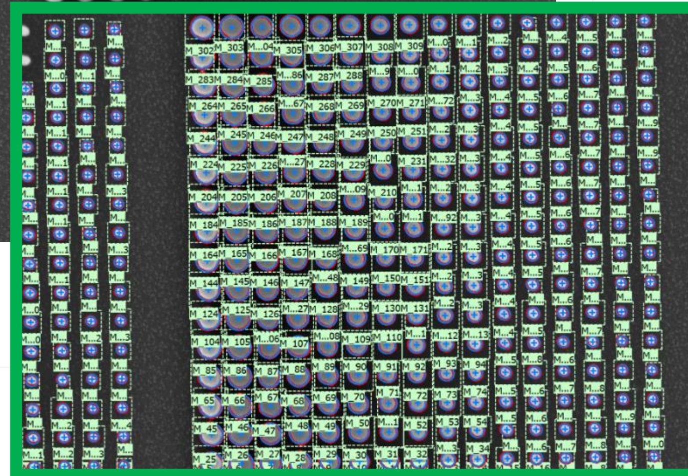
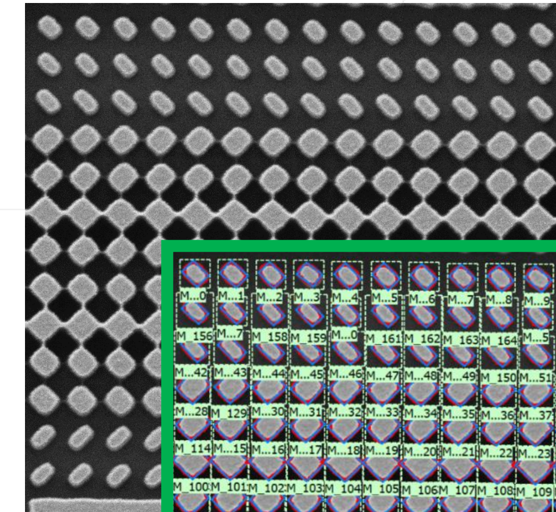
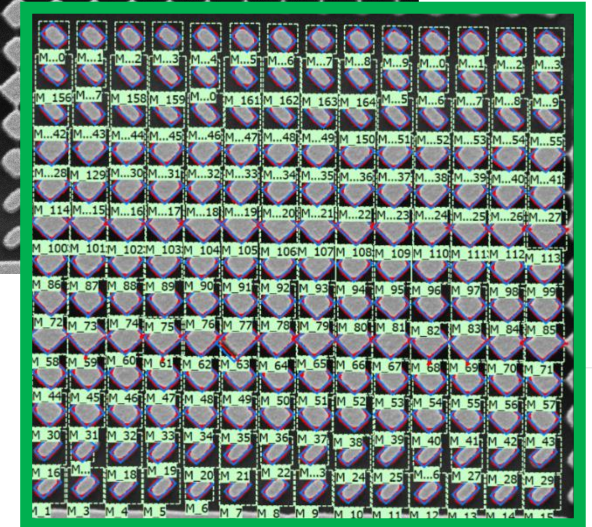
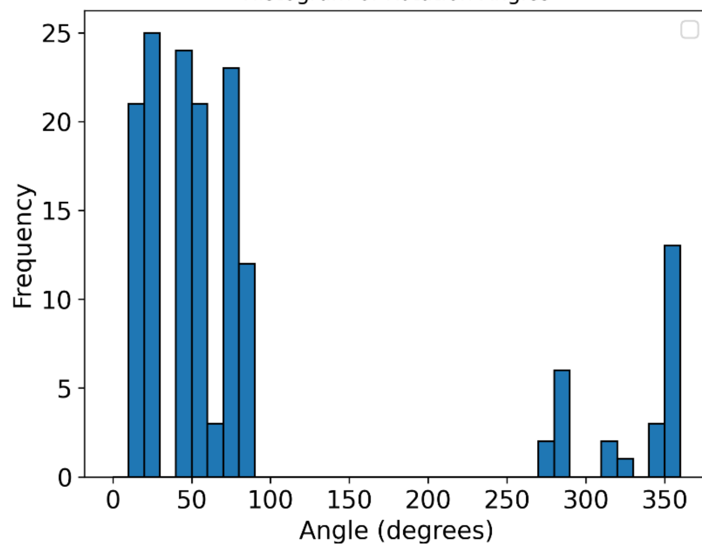
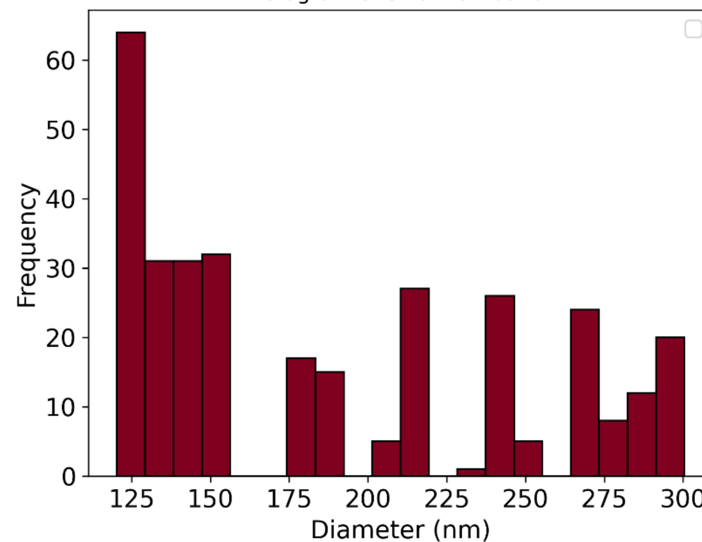
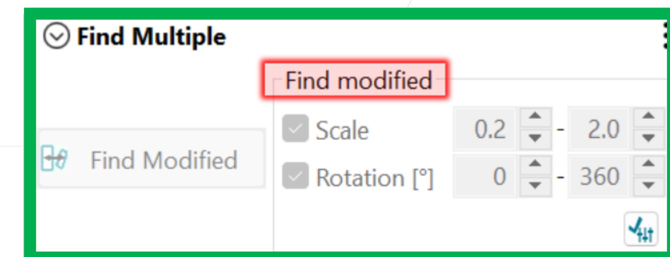
Nanostructure image analysis

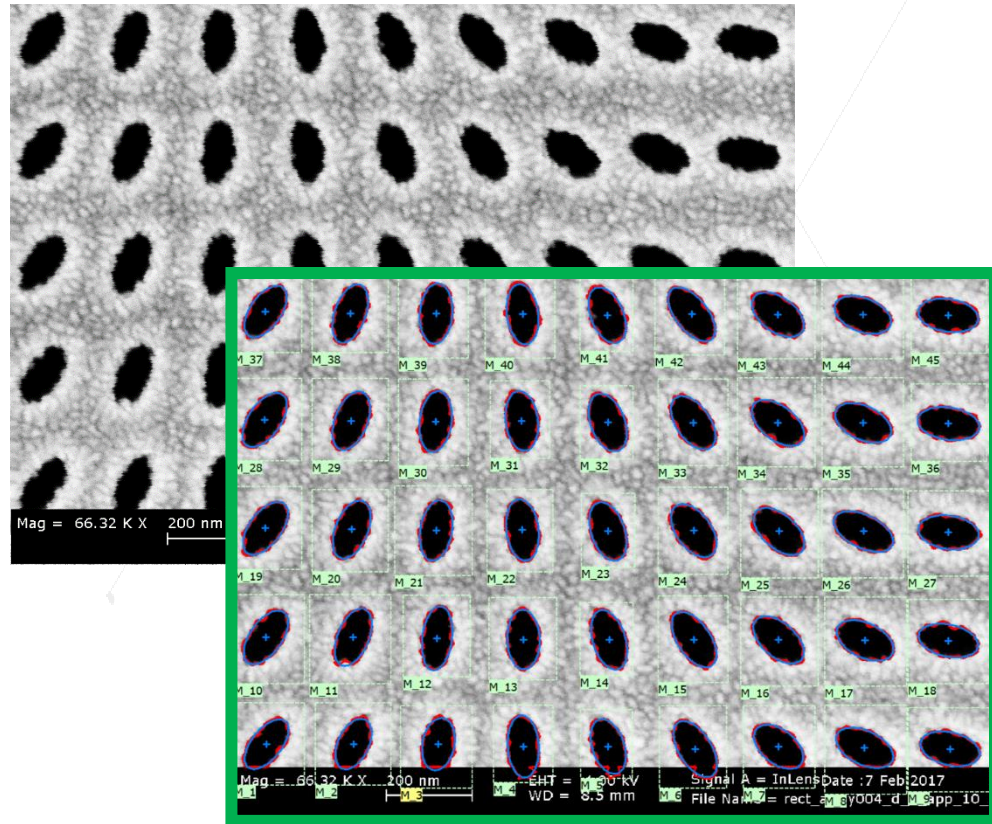










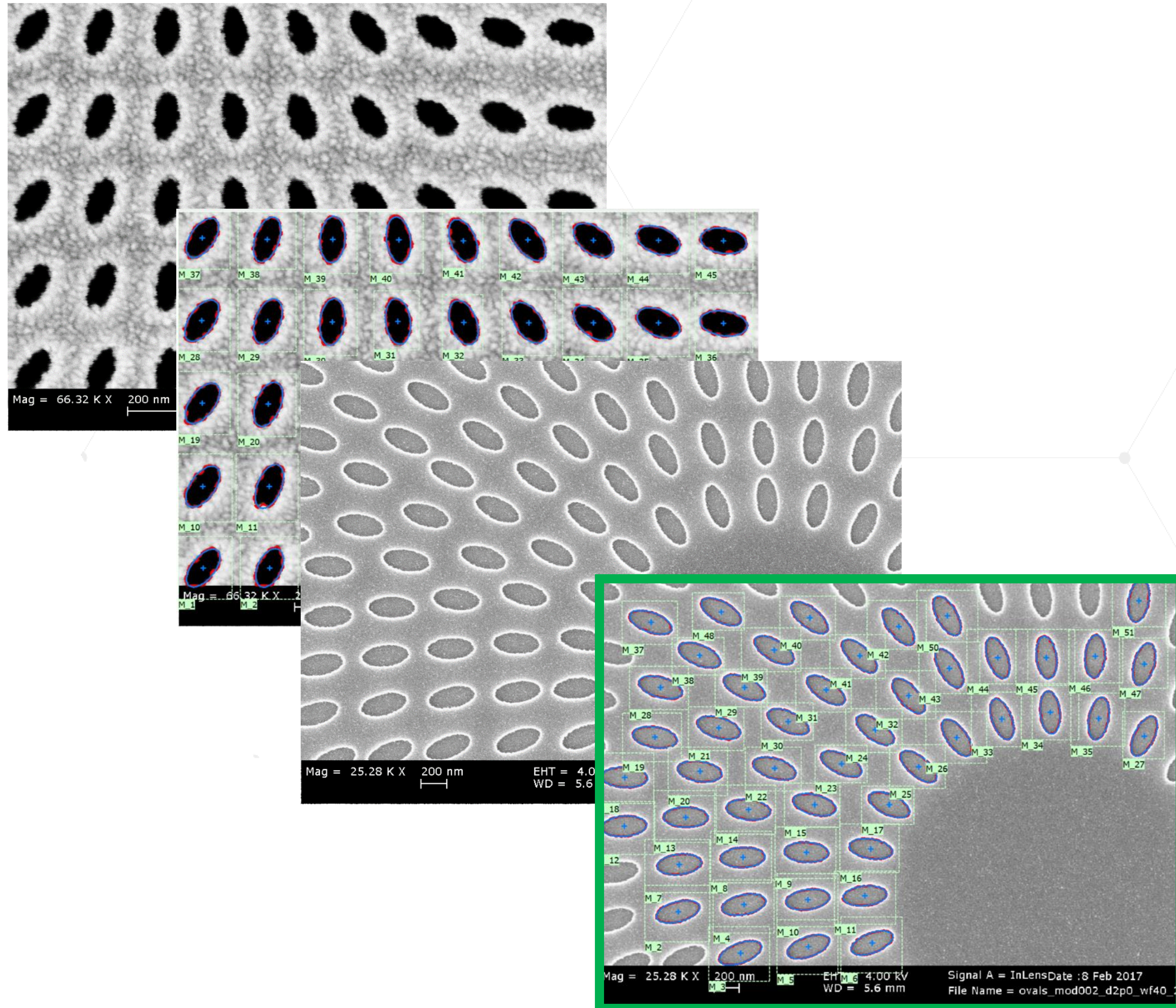


Find-modified: Isotropically scaled or rotated features

Nanostructure image analysis



Nanostructure image analysis



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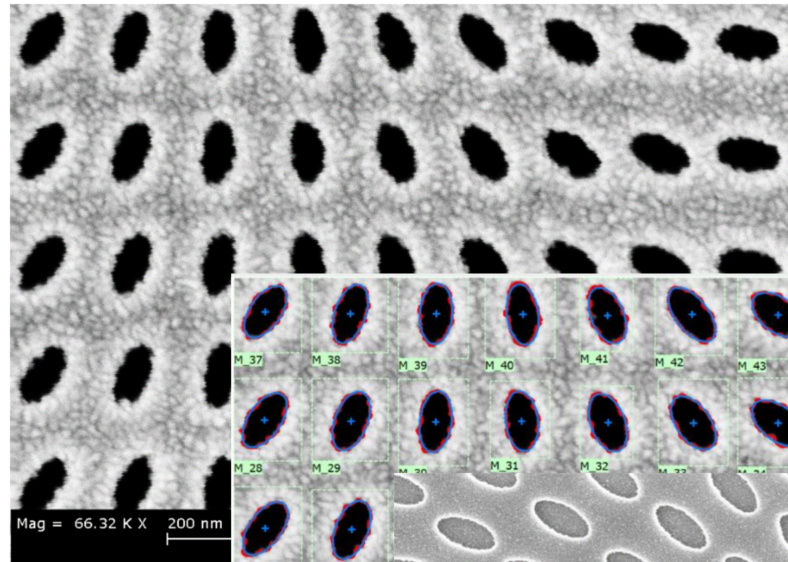
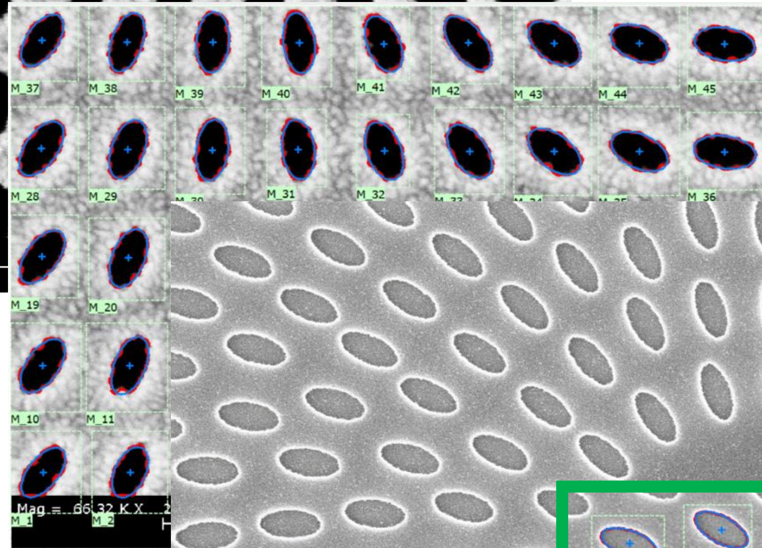
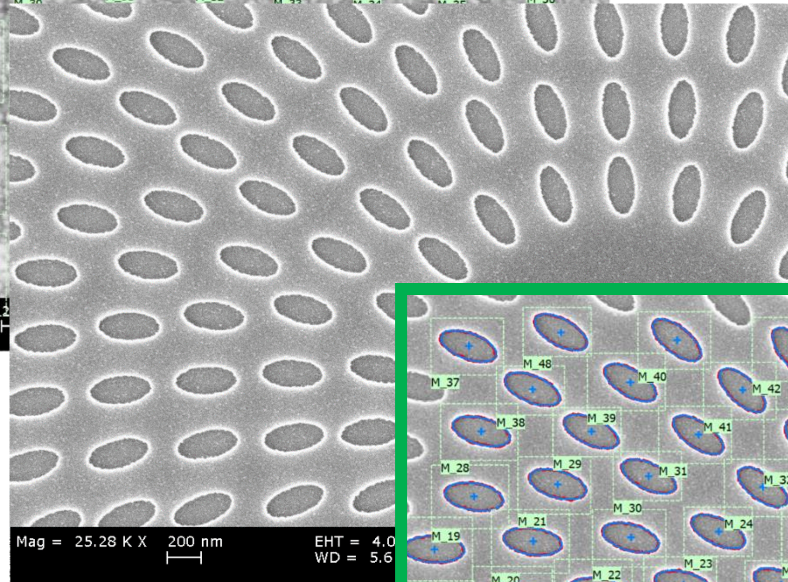
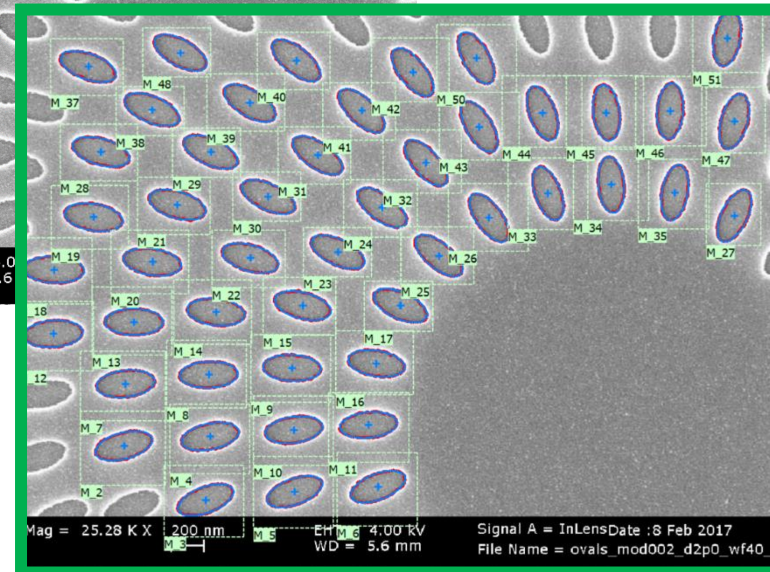
Nanostructure image analysis









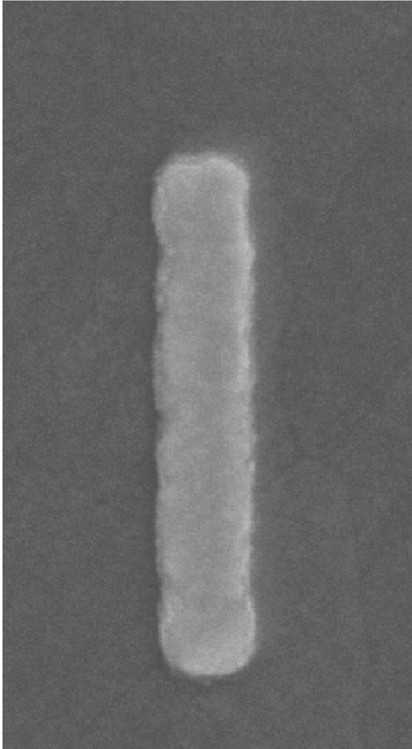
Measurement ID	Validation	AreaError
M_1	Success	-0.50%
M_3	Success	-0.43%
M_4	Success	-0.57%
M_5	Success	-0.61%
M_6	Success	-0.56%
M_7	Success	-0.54%
M_8	Success	-0.57%
M_9	Success	-0.63%
M_10	Success	-0.47%
M_11	Success	-0.75%
M_12	Success	-0.32%
M_13	Success	-0.50%
M_14	Success	-0.53%
M_15	Success	-0.26%
M_16	Success	-0.09%
M_17	Success	0.26%
M_18	Success	-0.38%
M_19	Validated	-0.55%
M_20	Success	-0.53%
M_21	Success	-0.70%
M_22	Validated	-0.55%
M_23	Validated	-0.53%
M_24	Success	-0.61%
M_25	Success	-0.45%
M_26	Validated	-0.20%
M_27	Validated	-0.60%
M_28	Success	-0.44%

Major Diameter[nm]	Minor Diameter[nm]	Aspect Ratio
141.8	70.4	0.496
130.3	71.9	0.552
128.9	74.4	0.577
152.0	72.4	0.476
137.9	74.3	0.538
151.8	76.6	0.504
134.3	81.1	0.604
143.7	81.9	0.570
140.5	80.1	0.570
150.0	75.1	0.501
147.5	72.7	0.493
156.9	68.7	0.438
145.5	75.6	0.520
149.4	75.9	0.508
152.4	77.6	0.509
143.4	81.0	0.565
143.0	83.2	0.582
141.0	77.8	0.552
147.0	75.0	0.511
147.4	75.5	0.512
147.3	73.7	0.500
149.6	74.7	0.499
146.3	78.0	0.533
144.6	81.9	0.567
143.1	79.8	0.558
149.8	79.2	0.529
141.7	80.9	0.571
149.4	76.0	0.509
148.8	76.0	0.511
149.3	74.0	0.496
146.6	75.0	0.511

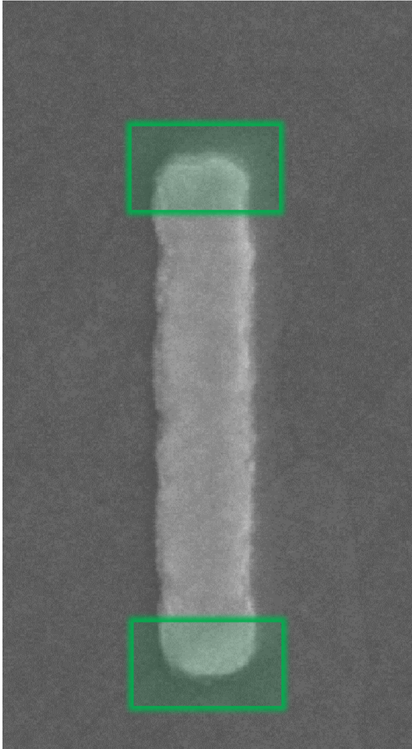
Feature Fit Quality
0.5739
0.6178
0.5451
0.6370
0.6214
0.6726
0.6372
0.6837
0.6578
0.6677
0.6183
0.6627
0.6824
0.6519
0.7096
0.6734
0.6619
0.6219
0.6943
0.6679
0.6660
0.6686
0.6986
0.6672
0.6322
0.7632
0.6864
0.6545

Corner Rounding

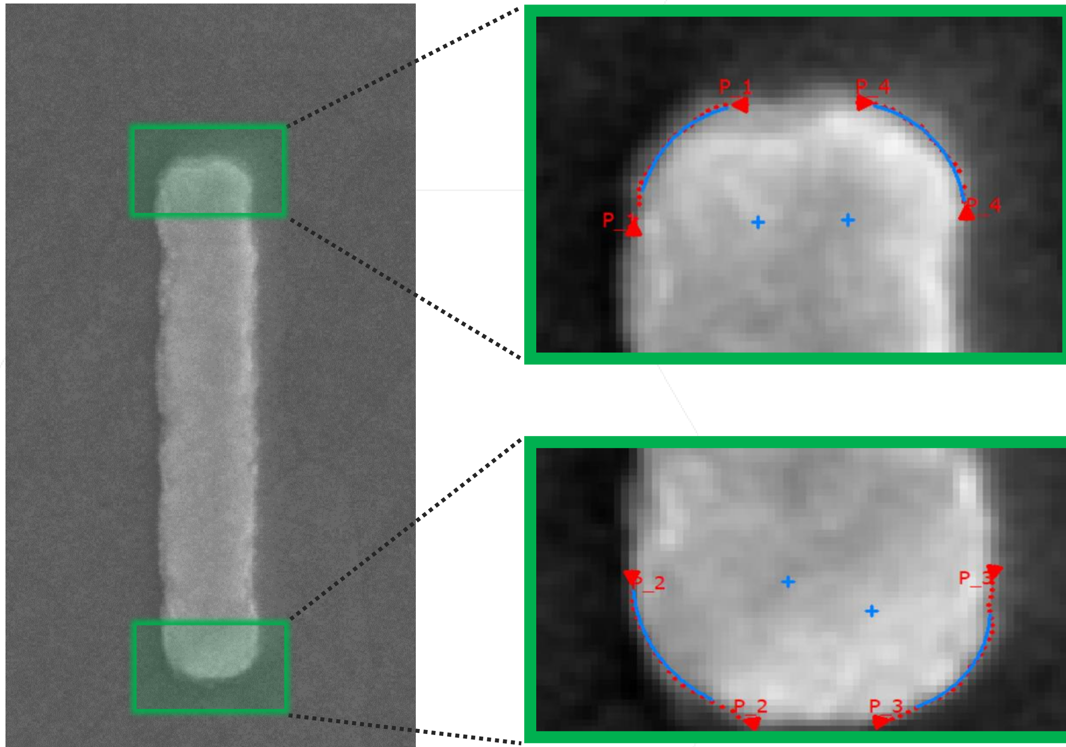
Corner Rounding



Corner Rounding



Corner Rounding



Feature Detection

Feature Type	Segmented Contour		
ROI [nm]	LL X 105.909	LL Y	143.818
	Width 303.112	Height	557.043

Edit Edge(s) Define Measurement...

Show Results

Name:	P_1	P_2	P_3	P_4
Position	Mid	Mid	Mid	Mid
CD %				
Method	Sigmoida	Sigmoida	Sigmoida	Sigmoida
Polarity	Rising	Rising	Falling	Falling
Fit	Arc	Arc	Arc	Arc

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Corner Rounding

EB363A
75x500

SEI 10.0kV X50,000 WD 3.6mm 100nm

Feature Detection

Feature Type	Segmented Contour			
ROI [nm]	LL X	105.909	LL Y	143.818
	Width	303.112	Height	557.043

Edit Edge(s) | Define Measurement... | Show Results

Name:	P_1	P_2	P_3	P_4
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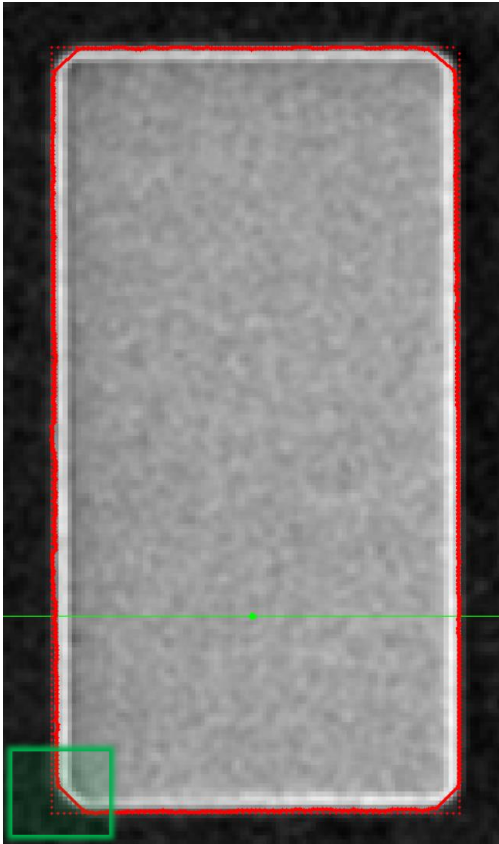
CD %				
Method	Sigmoida	Sigmoida	Sigmoida	Sigmoida
Polarity	Rising	Rising	Falling	Falling
Fit	Arc	Arc	Arc	Arc

P_1 Diameter[nm]	P_2 Diameter[nm]	P_3 Diameter[nm]	P_4 Diameter[nm]	P_1 Feature Fit Quality
44.2	36.3	86.5	58.1	0.3842
47.5	35.0	65.6	75.5	0.4786
36.3	74.0	56.8	50.4	0.1762
34.4	56.6	73.2	8.9	0.3310
62.6	76.9	58.7	61.9	0.4586
61.0	42.4	36.0	45.5	0.4951
				0.4586

Feature Fit Quality: Describes how well the chosen shape fits the measured edge points

Corner Rounding



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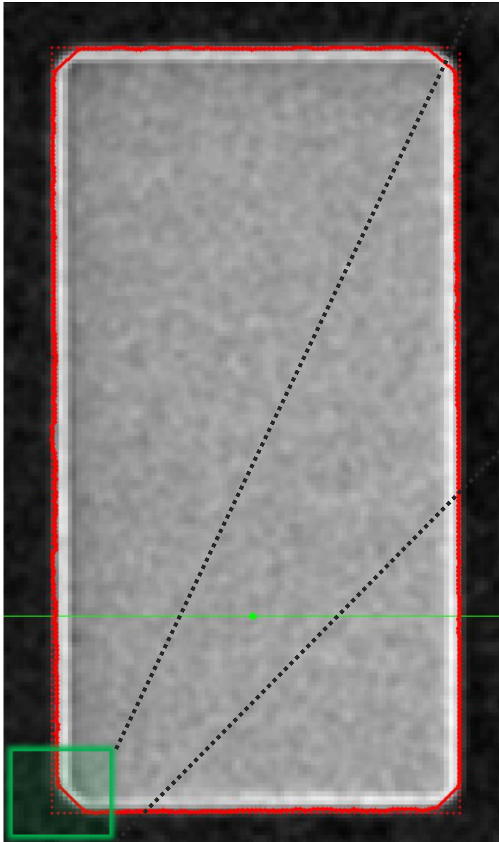
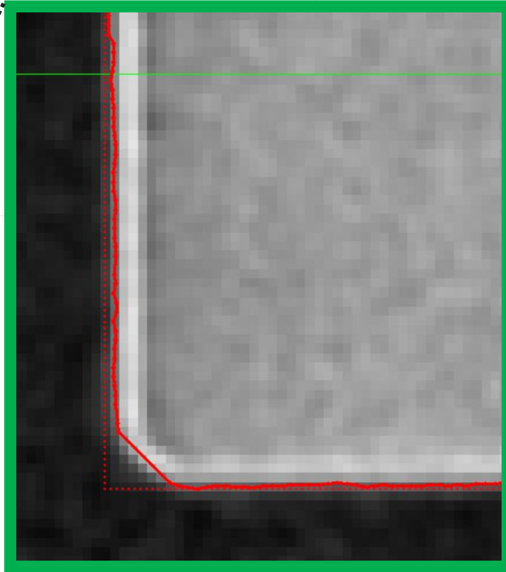
Corner Rounding





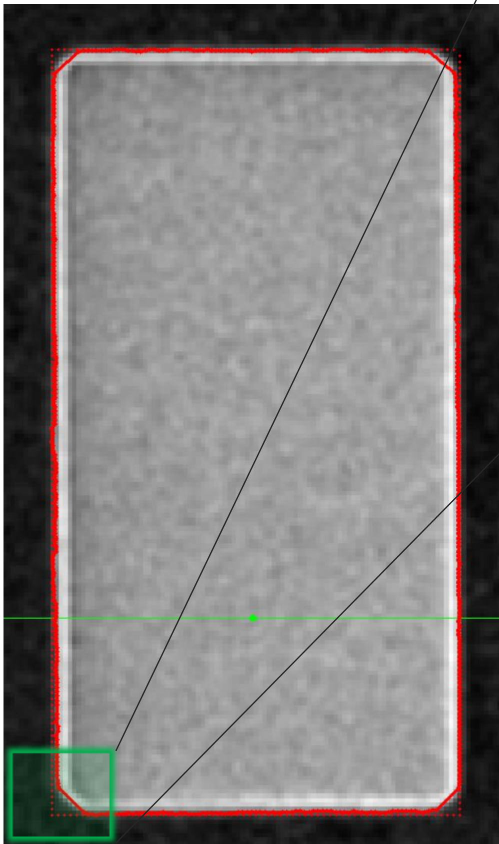
RectanglesArray_01 | Group_1 | M_3

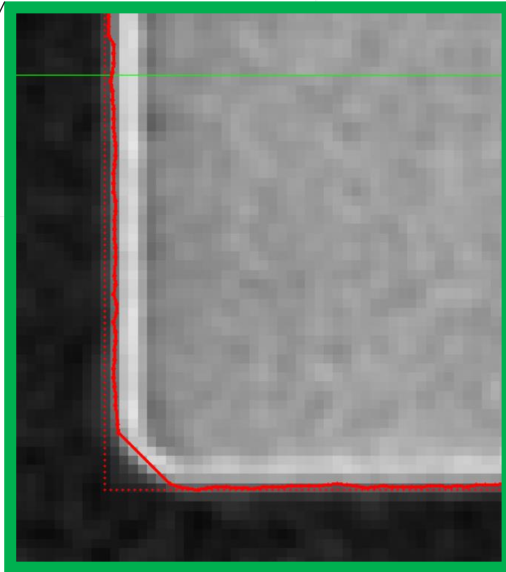
```
BBox Width[um]  : 10.7574
BBox Height[um] : 20.3727
Area[um^2]      : 214.6134
Slice S_1       : N.A.
Slice S_2       : N.A.
Slice S_3       : N.A.
Slice S_4       : N.A.
```

Variables:

```
BoundingBoxArea   = 219.16
ContourArea       = 214.61
DifferenceInAreas = 4.54
```

Corner Rounding





RectanglesArray_01 | Group_1 | M_3

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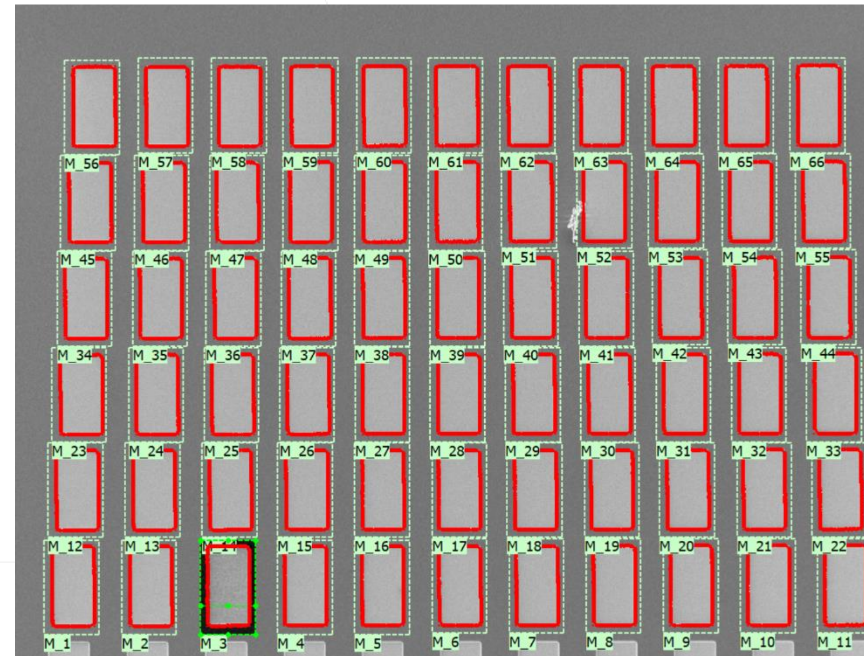
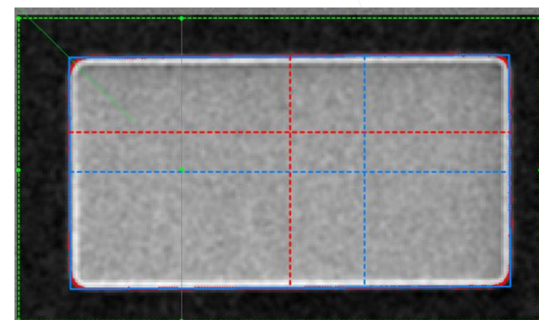




Measurement slices

Group Summary

…ntour Table | Shapes Array Table

		…t ID	Validation	BoundingBoxArea	ContourArea	DifferenceInAreas
			Success	220.05	215.57	4.48
			Success	220.36	214.31	6.05
			Success	219.16	214.61	4.54
			Success	221.42	215.13	6.29
			Success	217.77	213.18	4.59
			Success	218.90	213.77	5.13
			Success	218.32	213.71	4.61
			Success	219.42	214.32	5.11
			Success	217.83	213.66	4.17
			Success	217.90	213.61	4.29
			Success	218.66	214.08	4.57
			Success	220.43	215.71	4.72
			Success	219.85	214.81	5.04
			Success	218.91	214.15	4.76
			Success	218.66	214.39	4.27
			Success	217.60	213.20	4.40
			Success	218.13	213.77	4.35
			Success	217.83	213.78	4.05
			Success	218.88	214.55	4.33
RectanglesArray_01	Group_1	M_20	Success	217.78	213.58	4.20
RectanglesArray_01	Group_1	M_21	Success	218.22	213.83	4.39
RectanglesArray_01	Group_1	M_22	Success	218.14	213.97	4.17
RectanglesArray_01	Group_1	M_23	Success	219.44	215.18	4.27
RectanglesArray_01	Group_1	M_24	Success	218.75	214.64	4.11
RectanglesArray_01	Group_1	M_25	Success	218.54	214.09	4.45
RectanglesArray_01	Group_1	M_26	Success	218.62	214.61	4.00
RectanglesArray_01	Group_1	M_27	Success	217.01	213.06	3.95
RectanglesArray_01	Group_1	M_28	Success	218.07	213.82	4.26
RectanglesArray_01	Group_1	M_29	Success	218.21	213.70	4.51
RectanglesArray_01	Group_1	M_30	Success	219.08	214.35	4.73
RectanglesArray_01	Group_1	M_31	Success	218.57	213.63	4.94
RectanglesArray_01	Group_1	M_32	Success	217.43	213.54	3.90
RectanglesArray_01	Group_1	M_33	Success	219.54	213.49	6.06
RectanglesArray_01	Group_1	M_34	Success	220.73	216.08	4.64
RectanglesArray_01	Group_1	M_35	Success	219.39	214.53	4.86
RectanglesArray_01	Group_1	M_36	Success	219.80	215.12	4.68

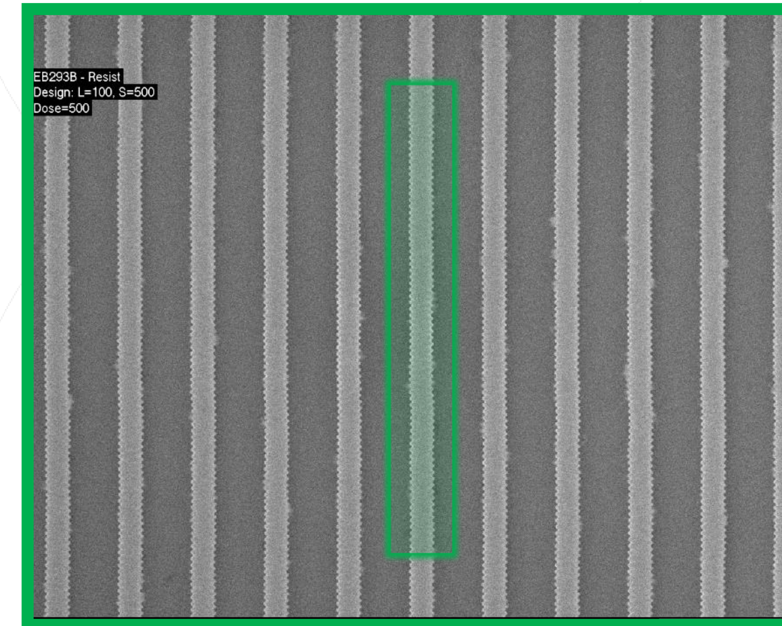
Bounding Box: Uses the outer bounds of the measured feature, along the image axis

Line Edge Roughness

Line Edge Roughness

Advanced LER and PSD

- LER (left/ right) and LWR reported per line
- Standard deviation (3-σ) from linear fit
- Power Spectral Density plot (PSD), white noise corrected
- Correlation length (ξ) and roughness exponent (α)
- PSD display and easy .csv export



Line Edge Roughness

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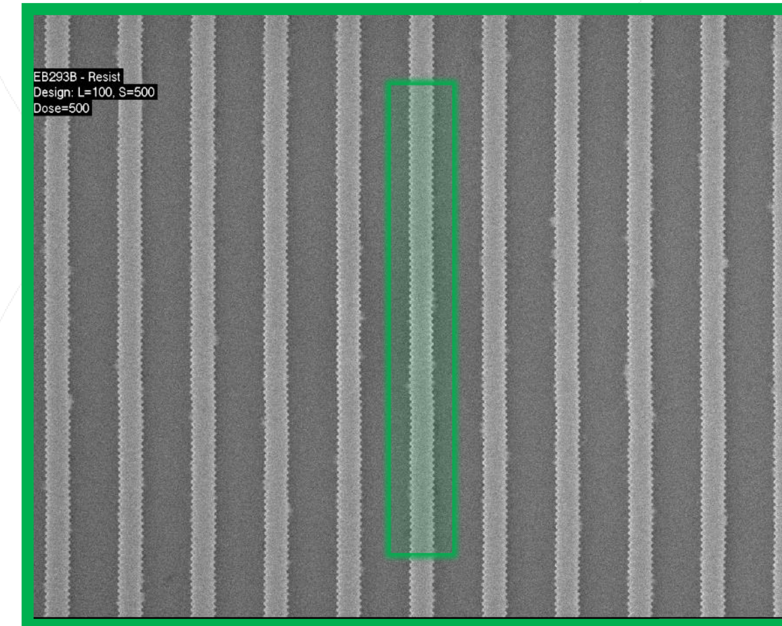
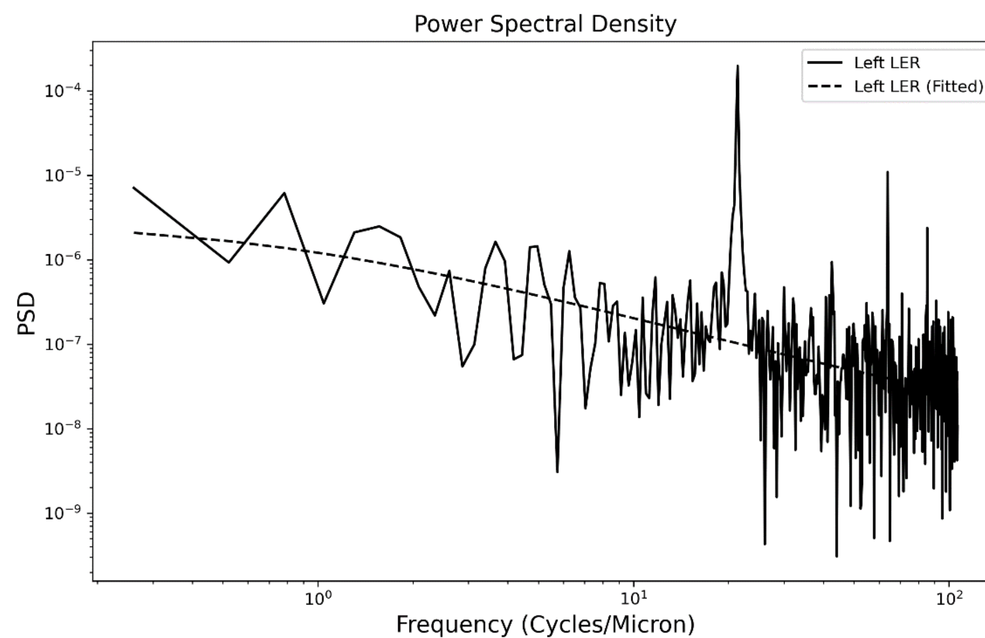
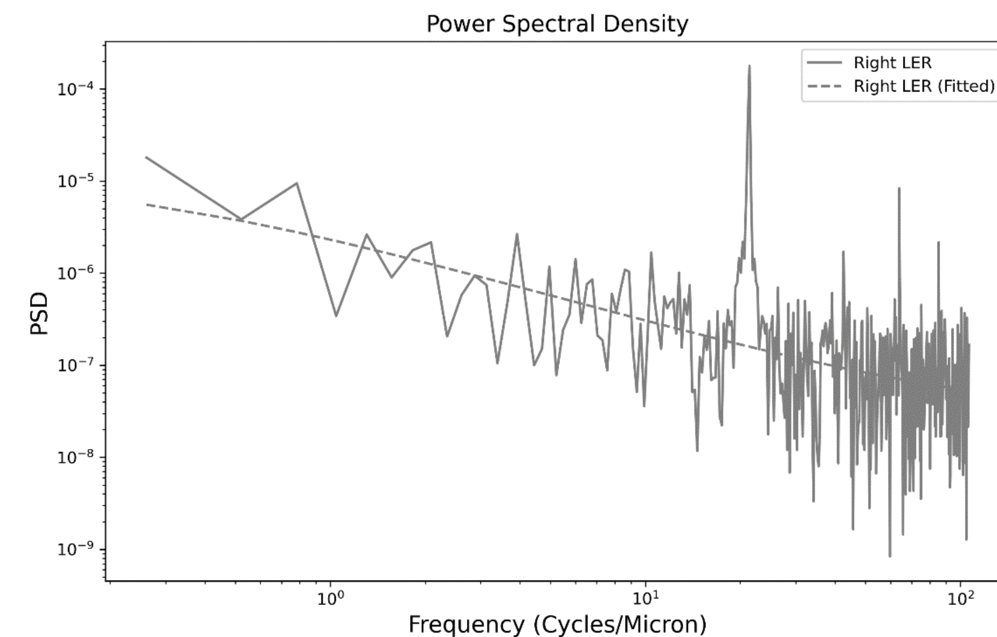
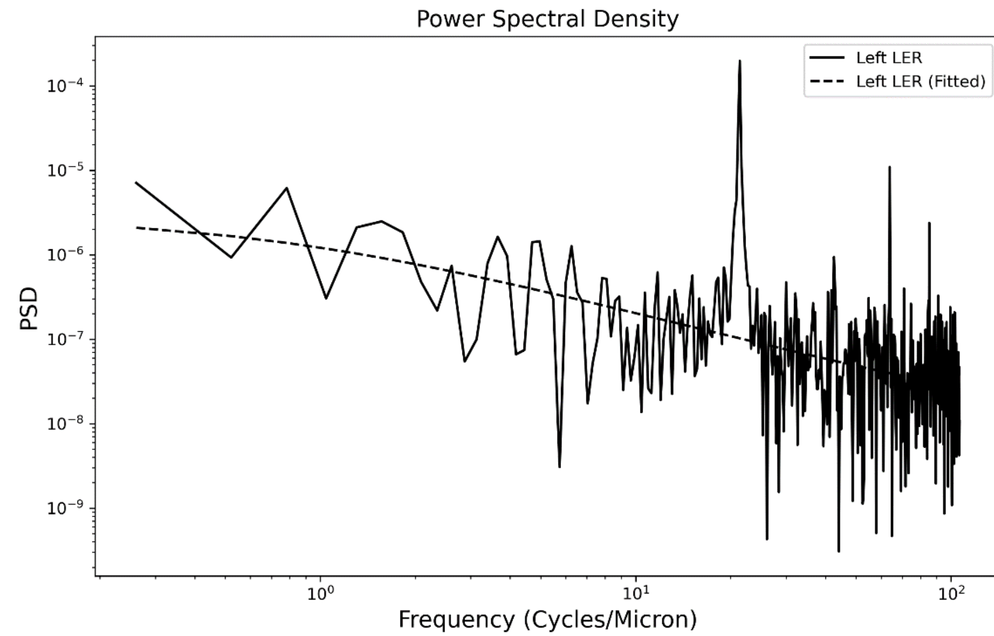
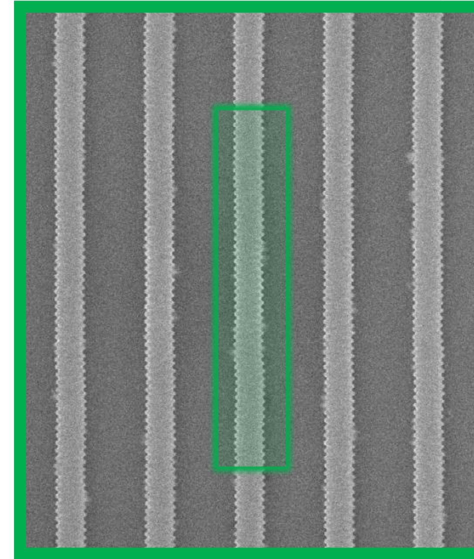


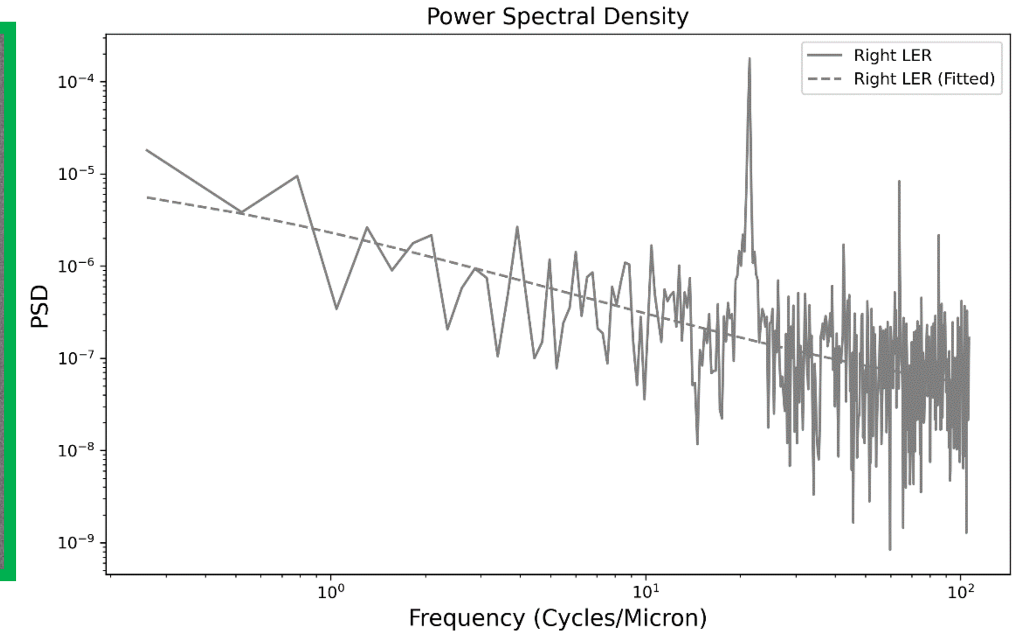


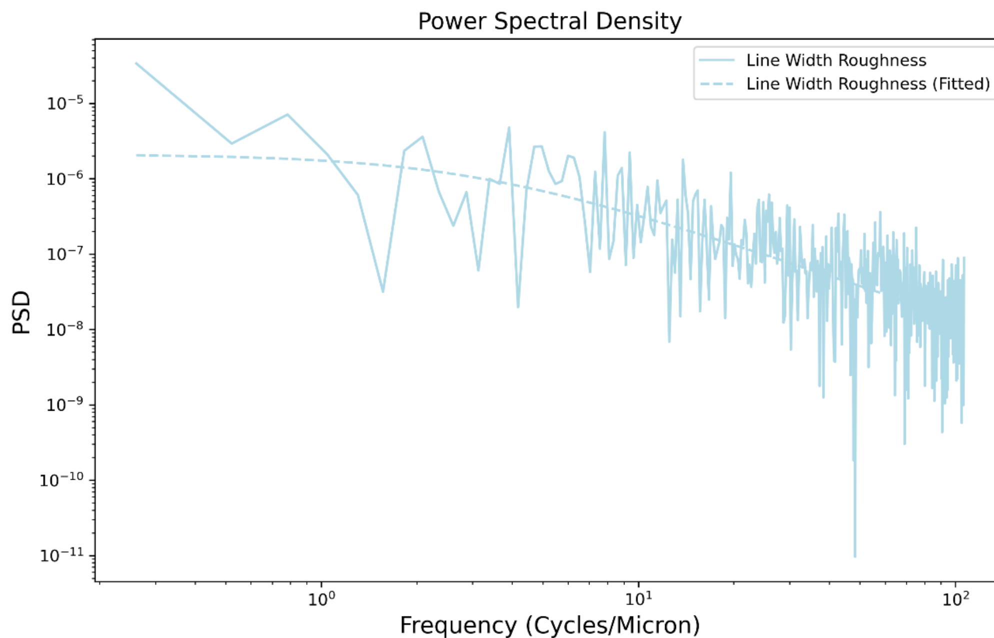


Line Edge Roughness







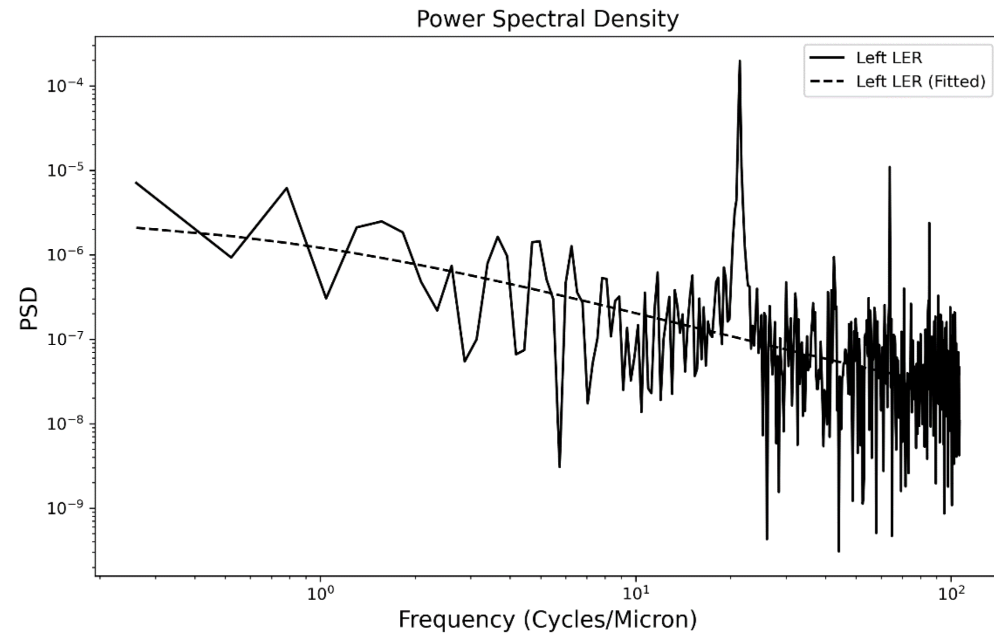


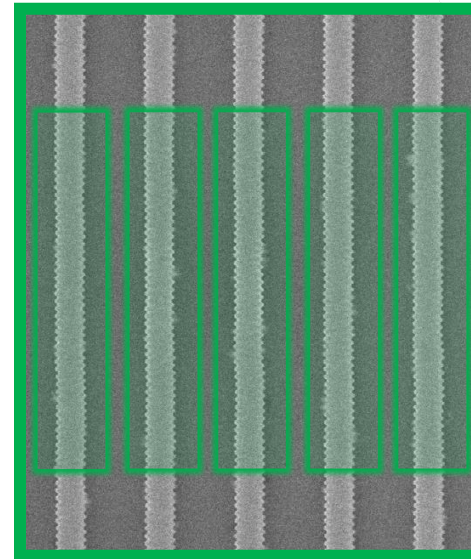
K__Line_Edge_Roughness | Lines & Spaces | Summary

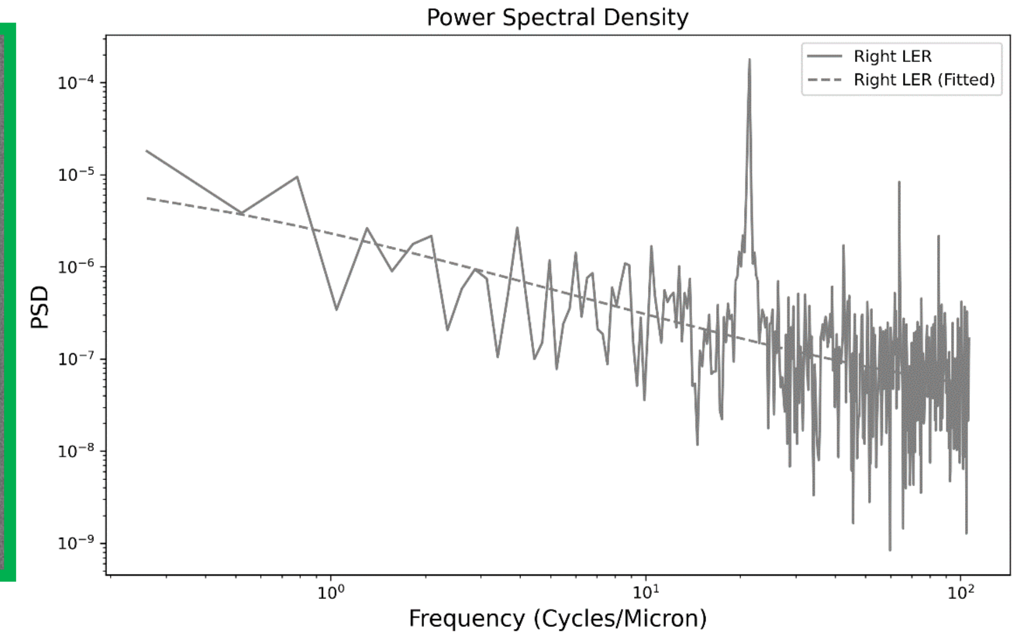
Parameter			Value		Min		Max
CD Mean[um]	:	Mean	= 0.1739	Min	= 0.1735	Max	= 0.1746
Rotation Mean[deg]	:	Mean	= 90.15	Min	= 90.11	Max	= 90.20
Left LER 3*StdDev[um]	:	Mean	= 0.0205	Min	= 0.0203	Max	= 0.0206
Left Correlation Length (Xi)[um]	:	Mean	= 0.9652	Min	= 0.4656	Max	= 1.3255
Left Roughness Exponent (Alpha)	:	Mean	= 0.0000	Min	= 0.0000	Max	= 0.0000
Right LER 3*StdDev[um]	:	Mean	= 0.0211	Min	= 0.0210	Max	= 0.0213
Right Correlation Length (Xi)[um]	:	Mean	= 2.5368	Min	= 1.1690	Max	= 3.8310
Right Roughness Exponent (Alpha)	:	Mean	= 0.0000	Min	= 0.0000	Max	= 0.0000
LWR 3*StdDev[um]	:	Mean	= 0.0119	Min	= 0.0114	Max	= 0.0129
LWR Correlation Length (Xi)[um]	:	Mean	= 0.2936	Min	= 0.2061	Max	= 0.3388
LWR Roughness Exponent (Alpha)	:	Mean	= 0.2323	Min	= 0.1912	Max	= 0.2953

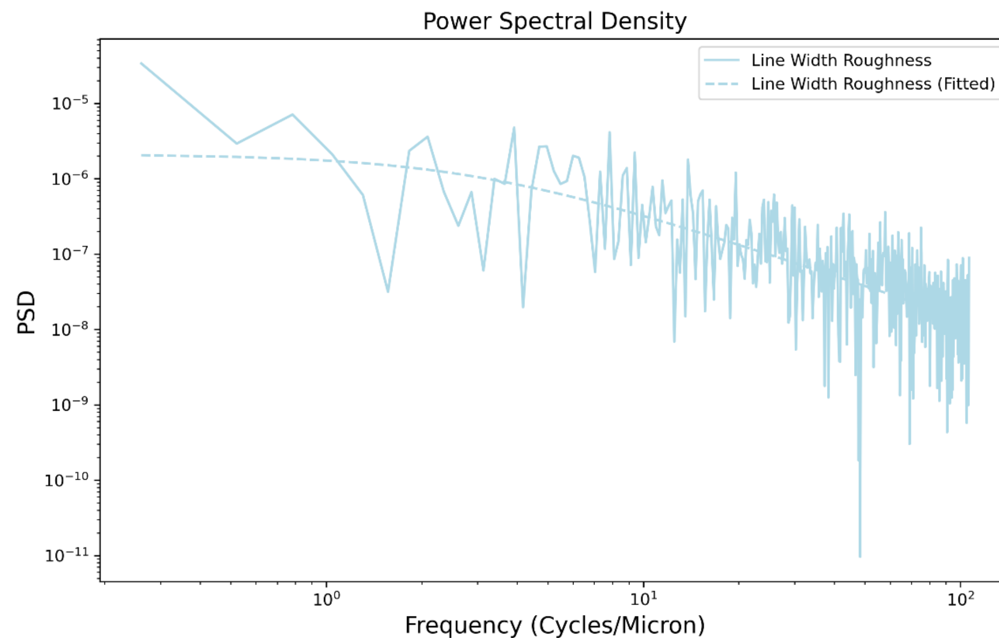
Line Edge Roughness

LER group average









K__Line_Edge_Roughness | Lines & Spaces | Summary

Parameter		Mean		Min		Max
CD Mean[um]	Mean	= 0.1739	Min	= 0.1735	Max	= 0.1746
Rotation Mean[deg]	Mean	= 90.15	Min	= 90.11	Max	= 90.20
Left LER 3*StdDev[um]	Mean	= 0.0205	Min	= 0.0203	Max	= 0.0206
Left Correlation Length (Xi)[um]	Mean	= 0.9652	Min	= 0.4656	Max	= 1.3255
Left Roughness Exponent (Alpha)	Mean	= 0.0000	Min	= 0.0000	Max	= 0.0000
Right LER 3*StdDev[um]	Mean	= 0.0211	Min	= 0.0210	Max	= 0.0213
Right Correlation Length (Xi)[um]	Mean	= 2.5368	Min	= 1.1690	Max	= 3.8310
Right Roughness Exponent (Alpha)	Mean	= 0.0000	Min	= 0.0000	Max	= 0.0000
LWR 3*StdDev[um]	Mean	= 0.0119	Min	= 0.0114	Max	= 0.0129
LWR Correlation Length (Xi)[um]	Mean	= 0.2936	Min	= 0.2061	Max	= 0.3388
LWR Roughness Exponent (Alpha)	Mean	= 0.2323	Min	= 0.1912	Max	= 0.2953

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2D Line Edge Roughness

Edge roughness analysis for 2D shapes

- LER extended to fitted 2D features
- Circles, ellipses, rectangle, and triangles
- Standard deviation (3-σ) relative to fitted shape

- PSD plot with fit corrected for white noise
- Deviations at corners are excluded
- Correlation length (ξ) and roughness exponent (α)

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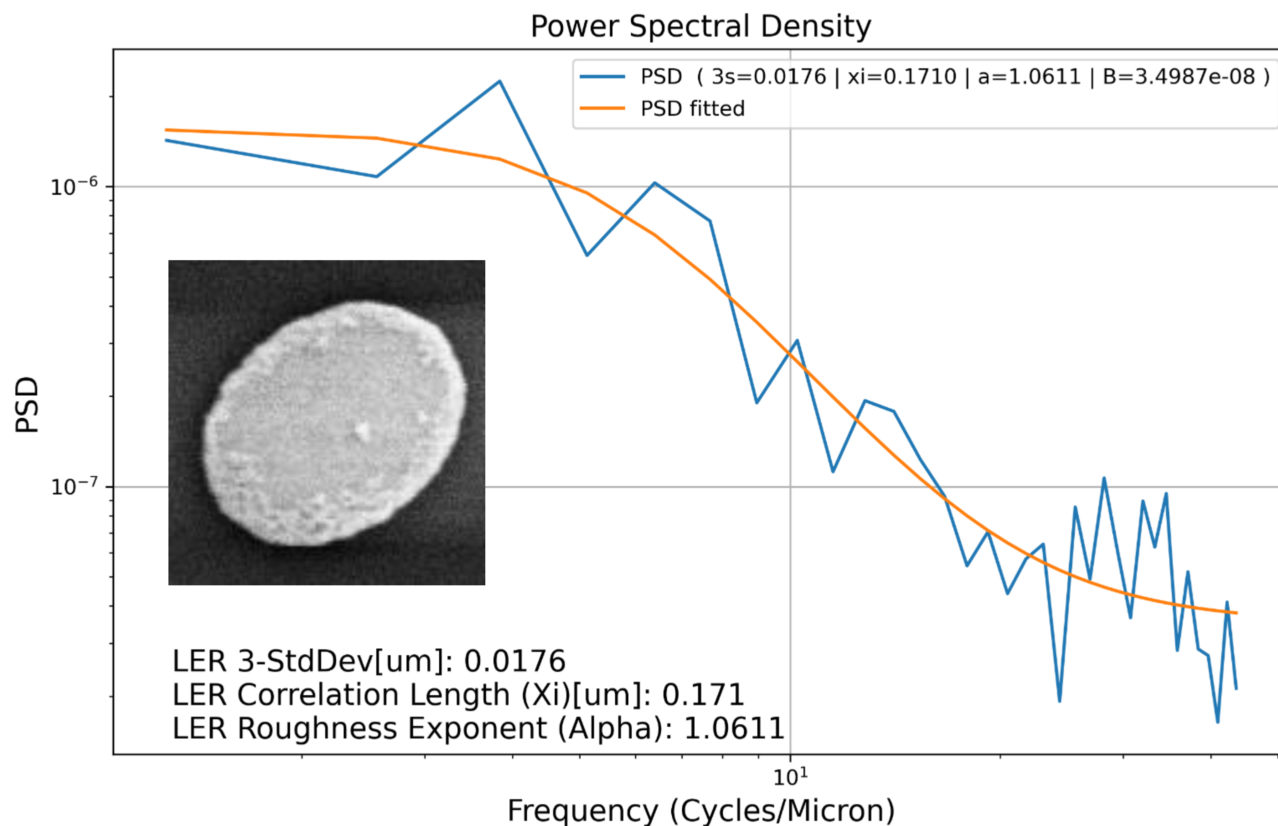
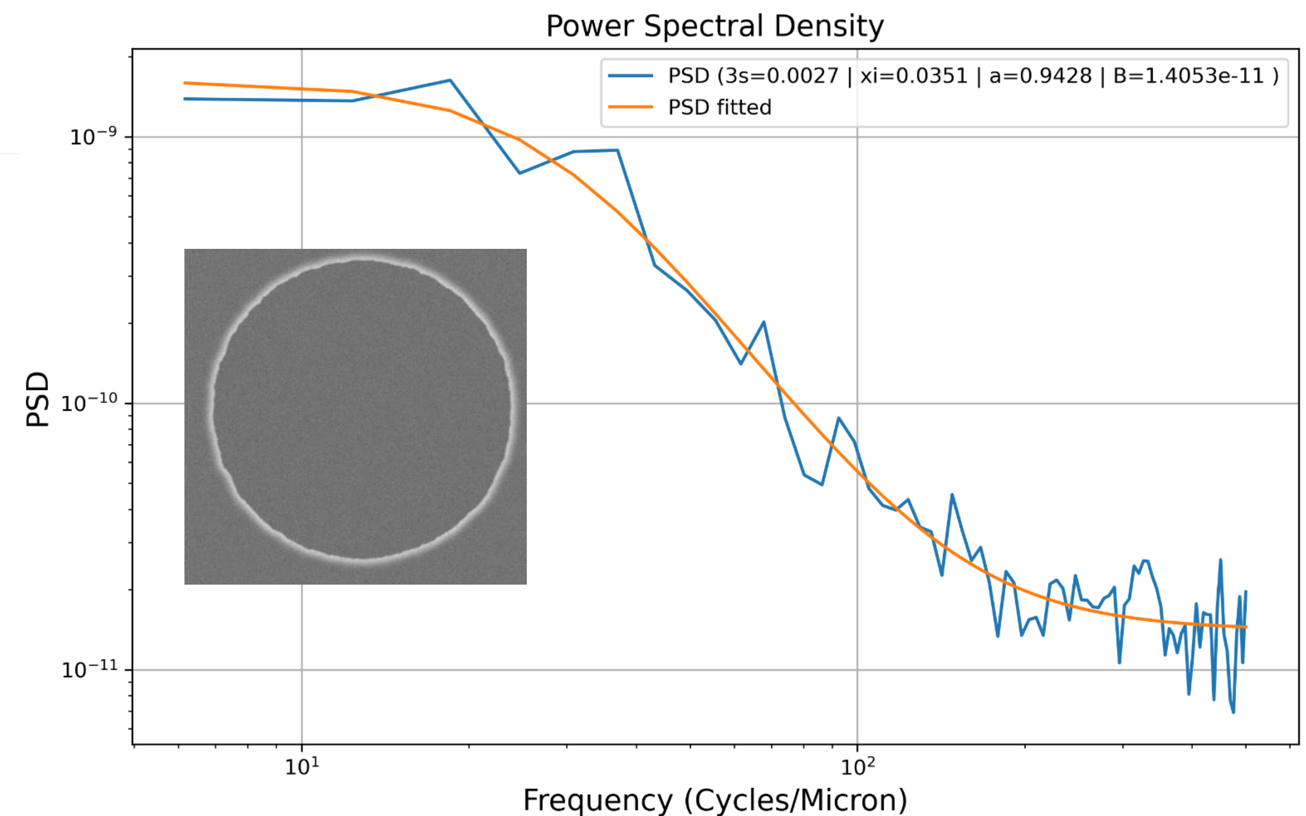
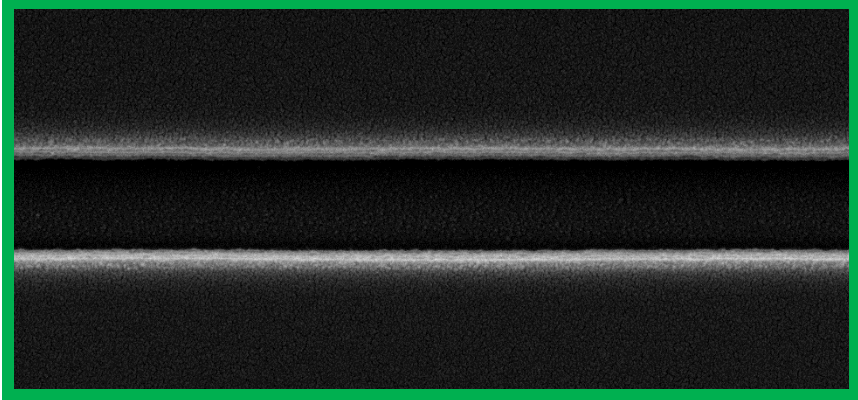
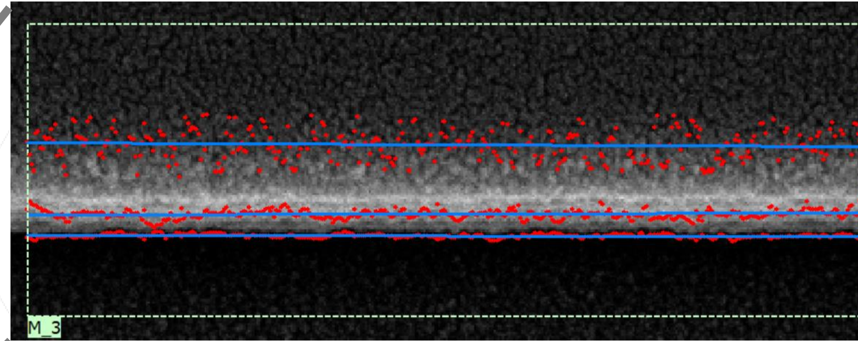


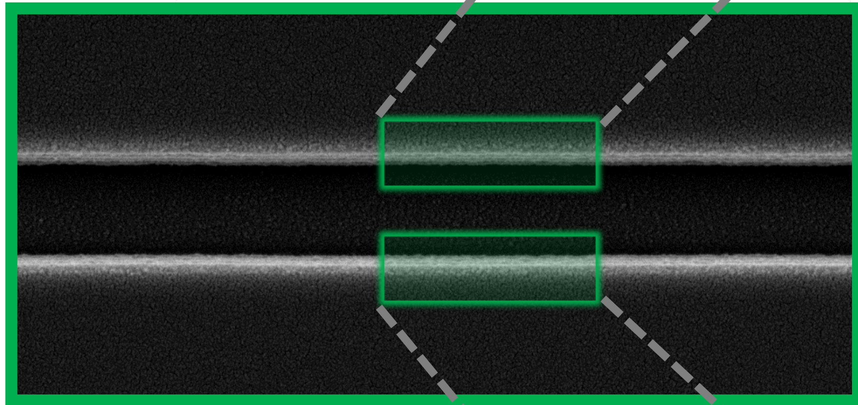


Side-wall analysis



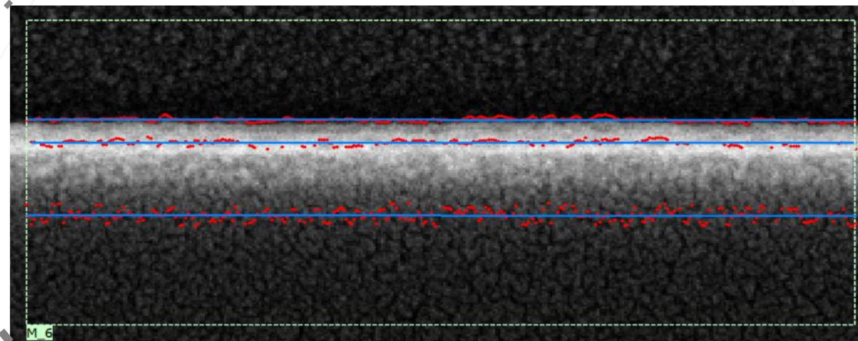
Side-wall analysis





Single Edge Measurement

- Define **Edge polarity** (Rising/Falling)
- Set the **Signal position** to define the part of the feature
- Inner and outer side-wall widths



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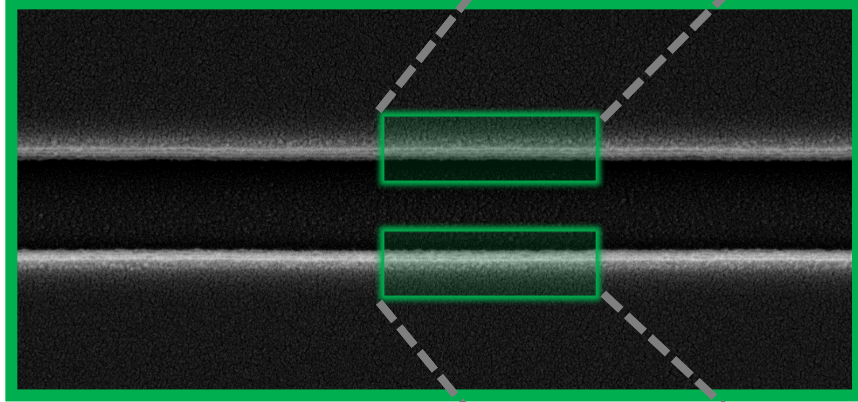
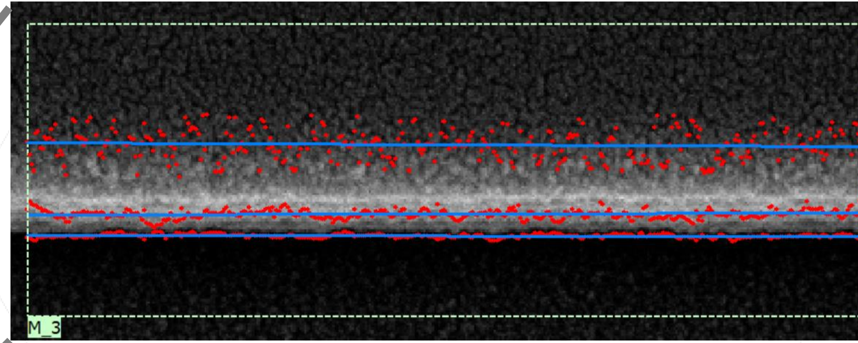
Side-wall analysis





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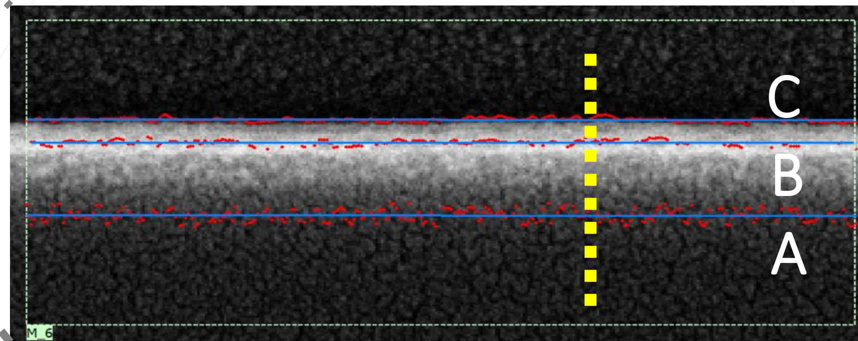
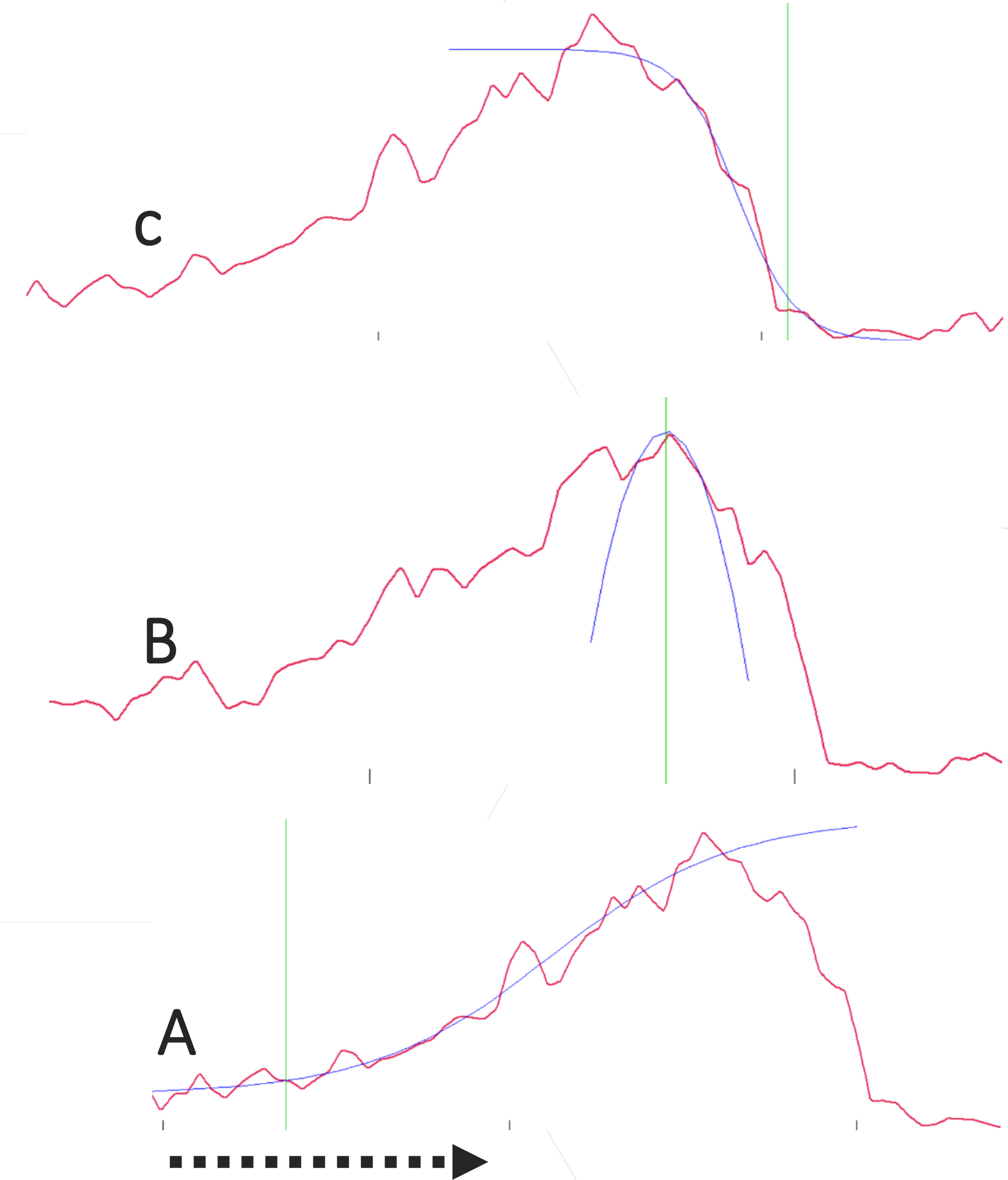
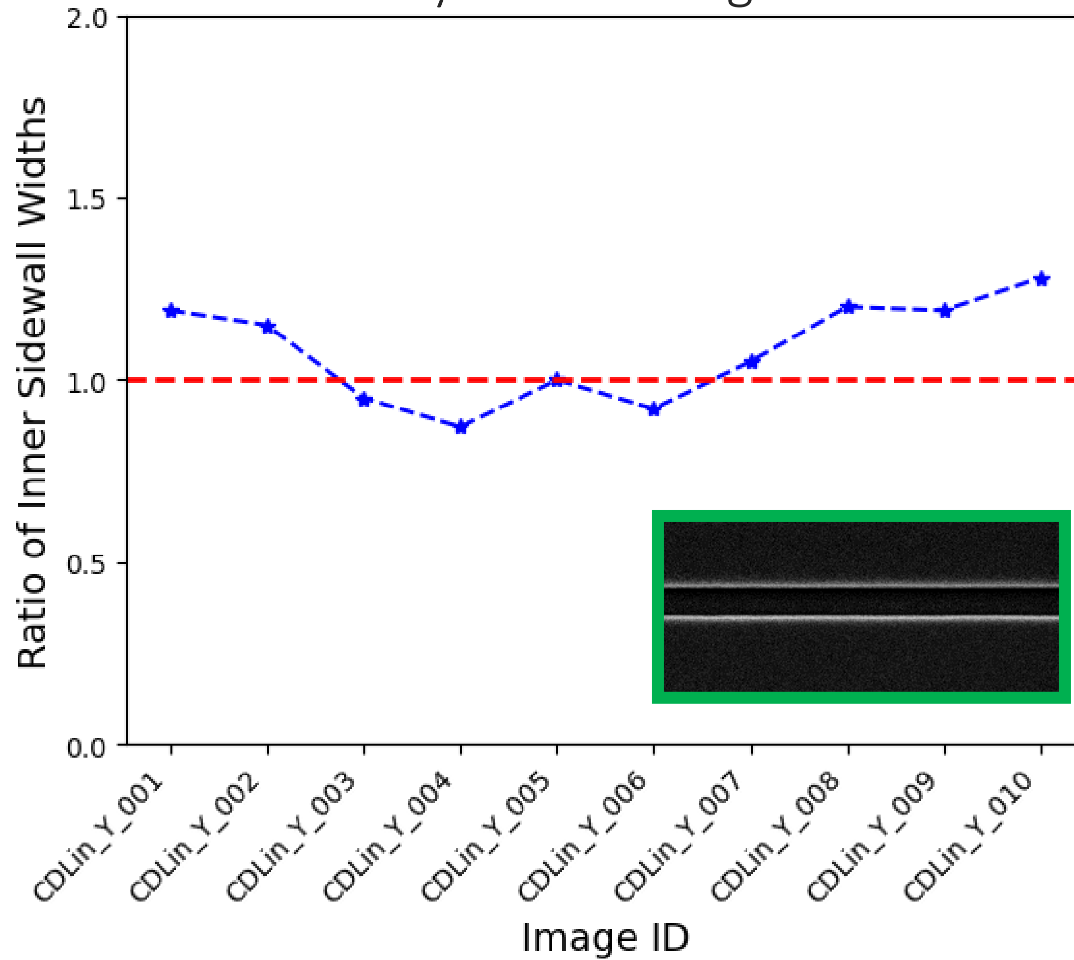
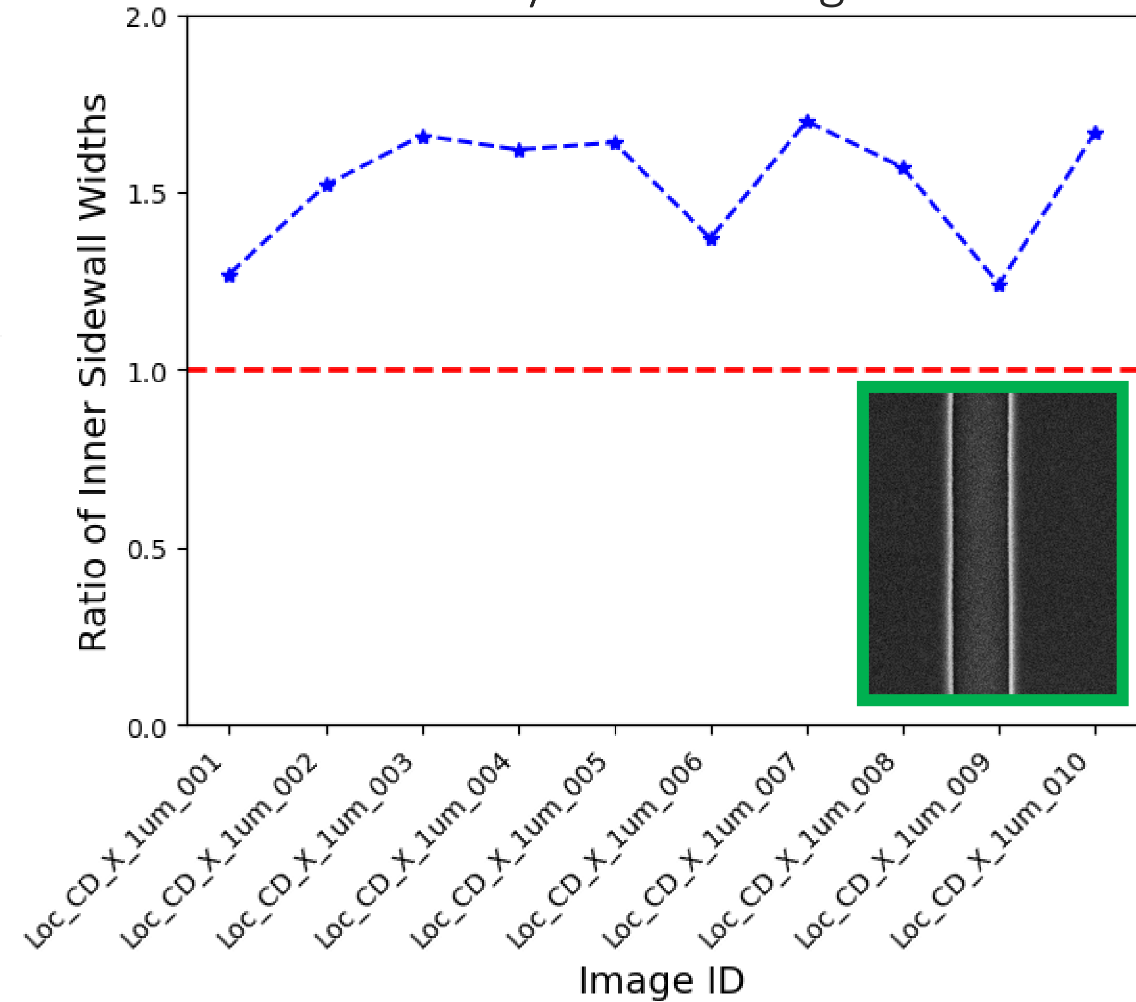




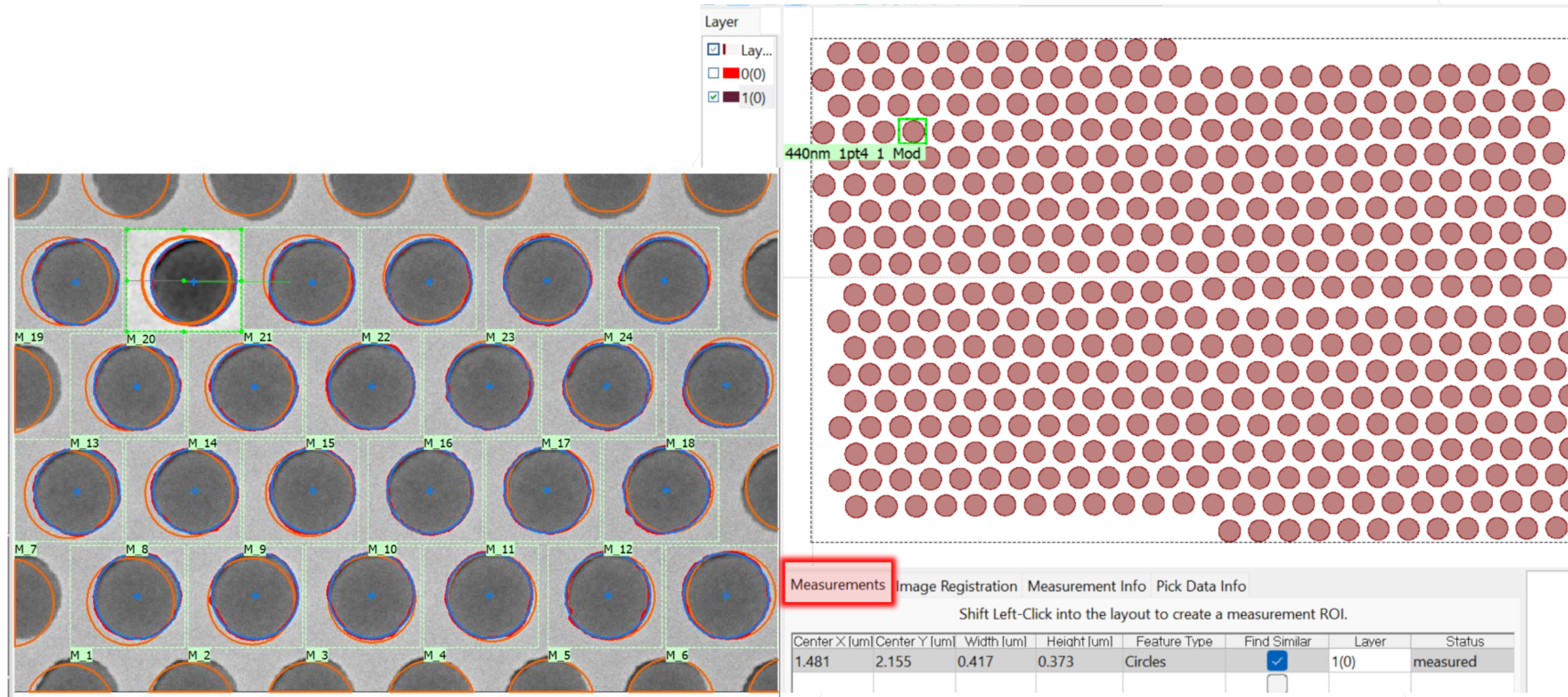
Side-wall analysis

Batch processing & determination of side-wall symmetry

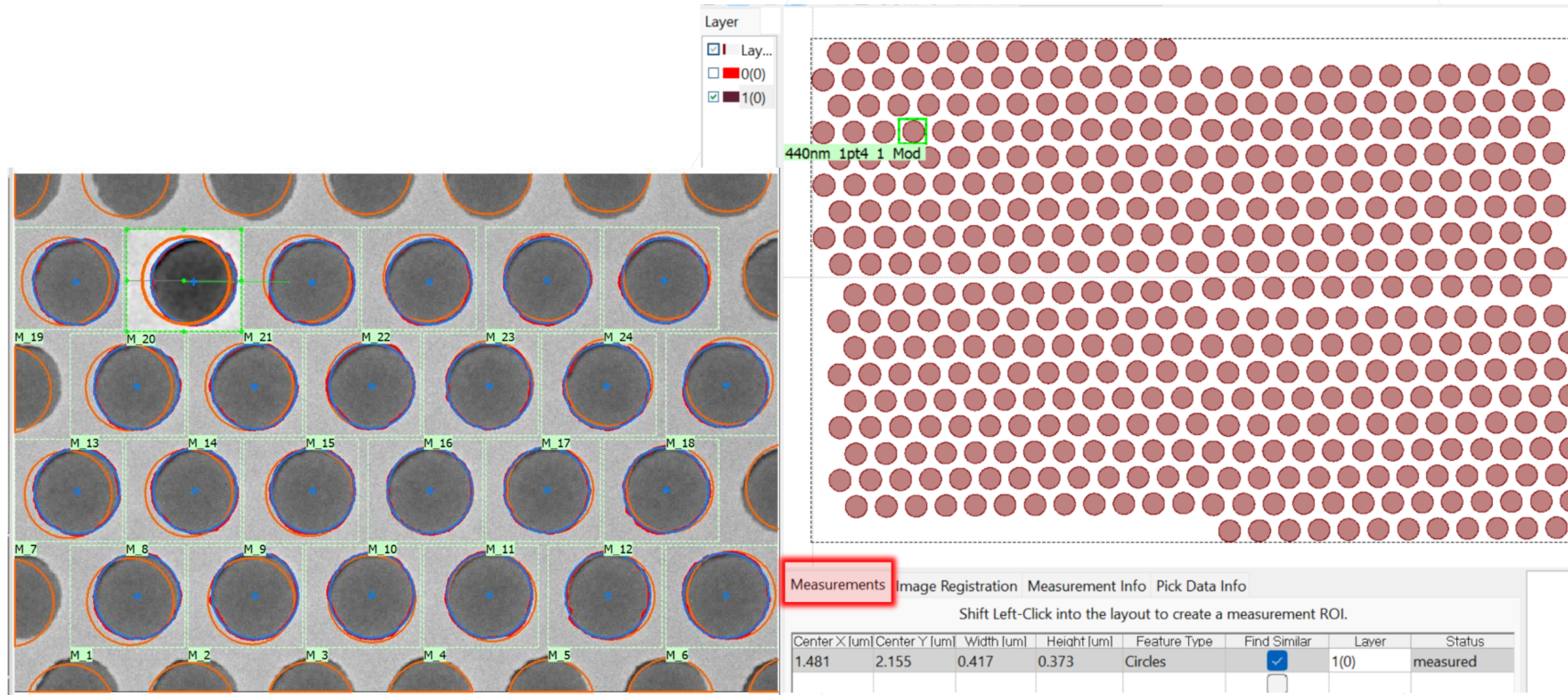




Layout-based metrology



Layout-based metrology



Measurements | Image Registration | Measurement Info | Pick Data Info

Options

- [x] Enable Scale Alignment
- [x] Enable Rotation Alignment
- [x] Enable Downsampling by Factor 1

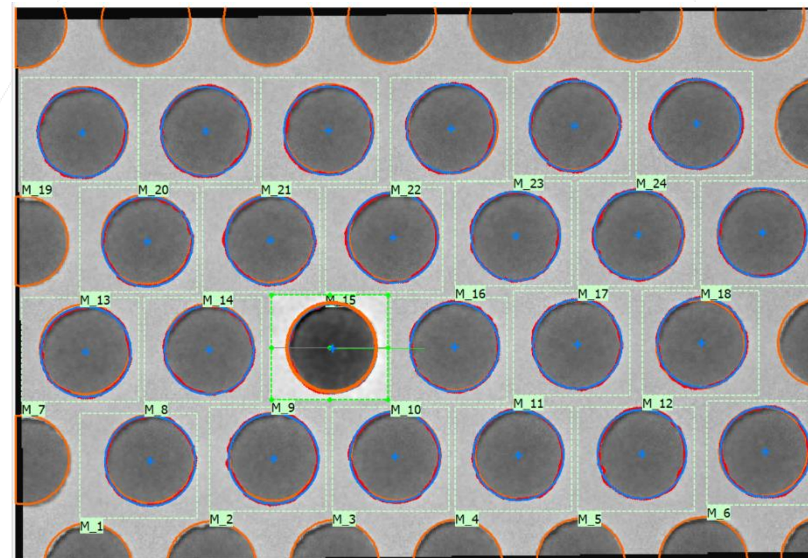
Re-Registration

- [x] Registration on Link

Register Current

Register Unregistered

Register All



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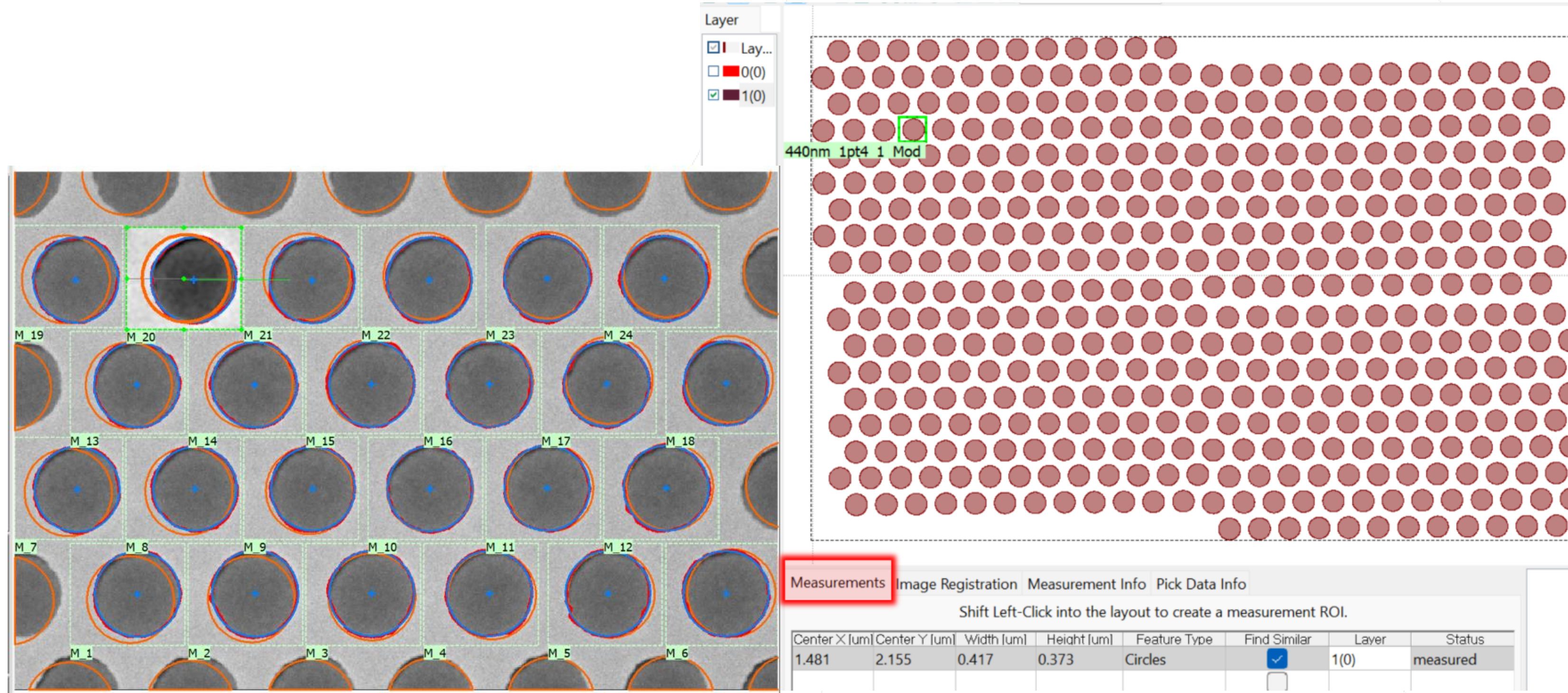

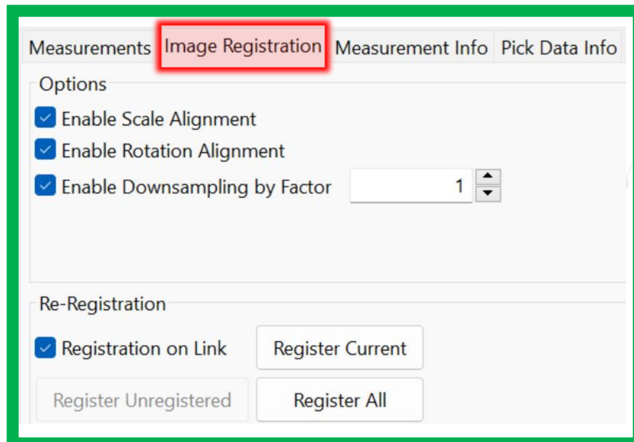

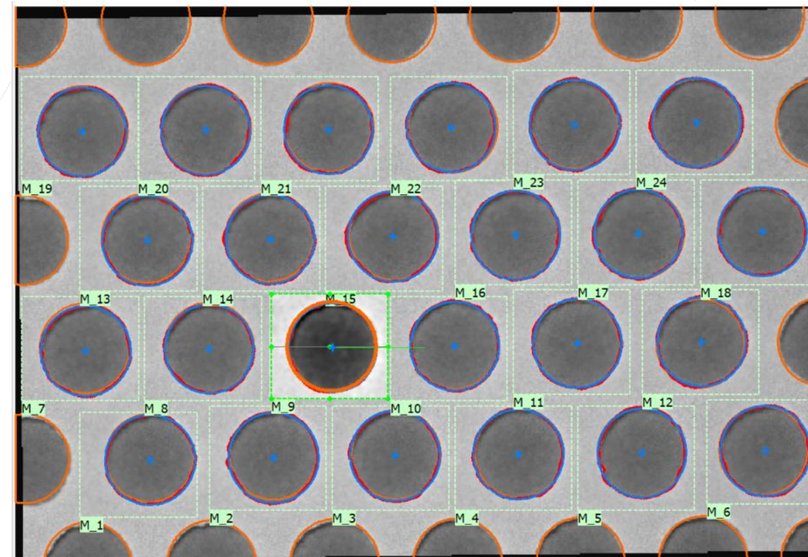

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HexArray_280nm_440nm_1pt4_1_Mod_1	Group_1	M_2
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LayoutShiftX[nm]	LayoutShiftY[nm]
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-0.2	-6.5
-2.9	-4.5
-3.4	-2.9
1.9	-1.1
7.6	-2.0
4.6	-9.3
1.4	-5.0
3.2	-4.1
0.6	-3.4
-1.3	1.7
4.6	4.2
3.8	-8.0
2.2	-6.7
-4.8	-4.3
-1.9	-1.6
-2.8	-0.7
2.6	2.4
-1.6	-4.0
-3.3	-4.5
-1.4	-6.5
-6.2	0.8
-0.0	-0.8
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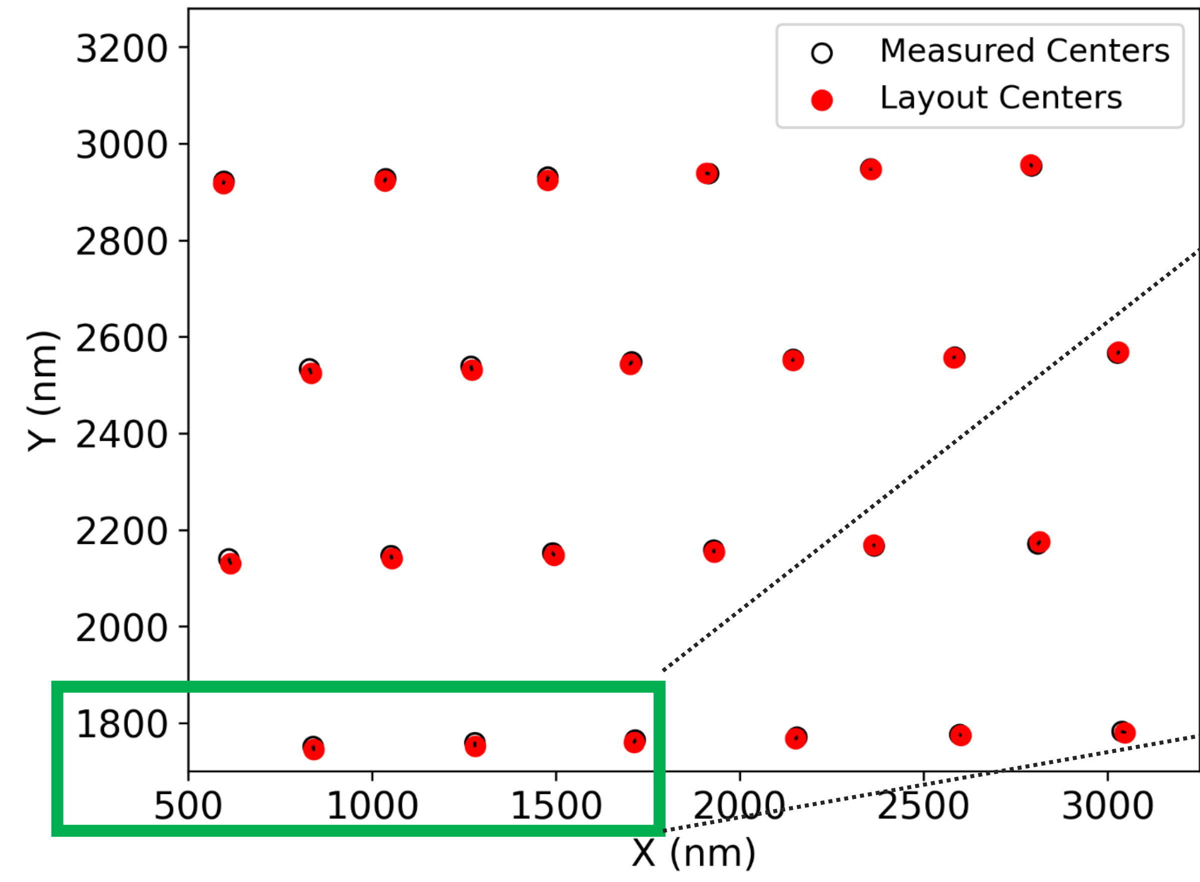
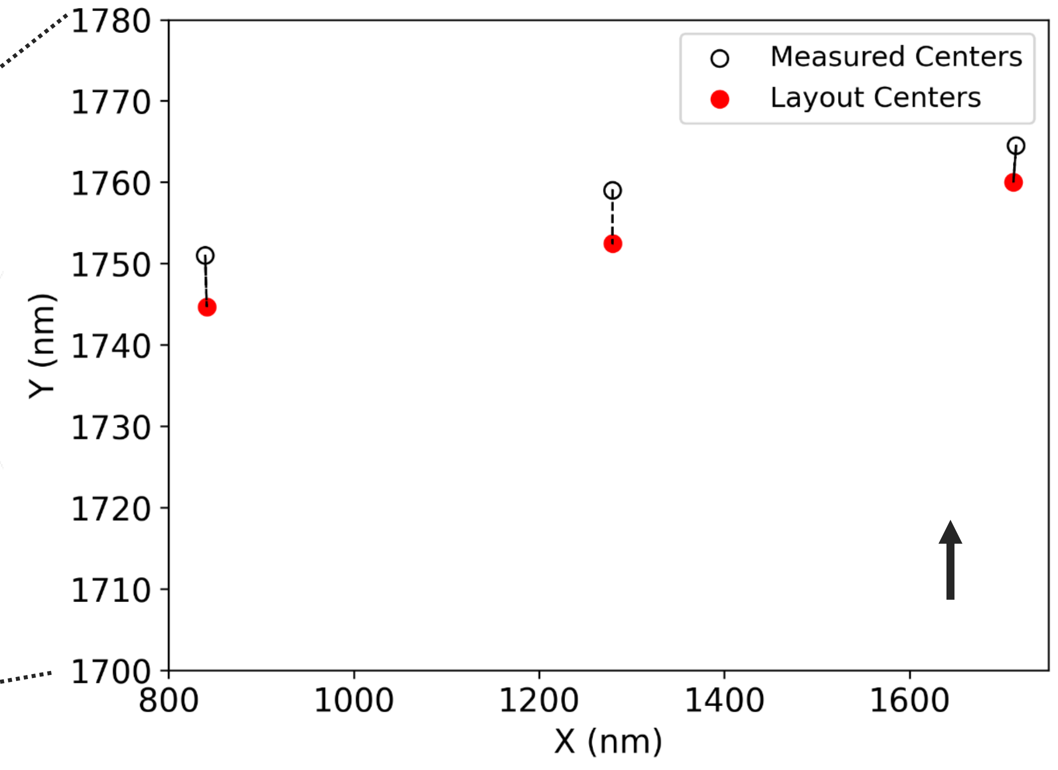
Placement Analysis





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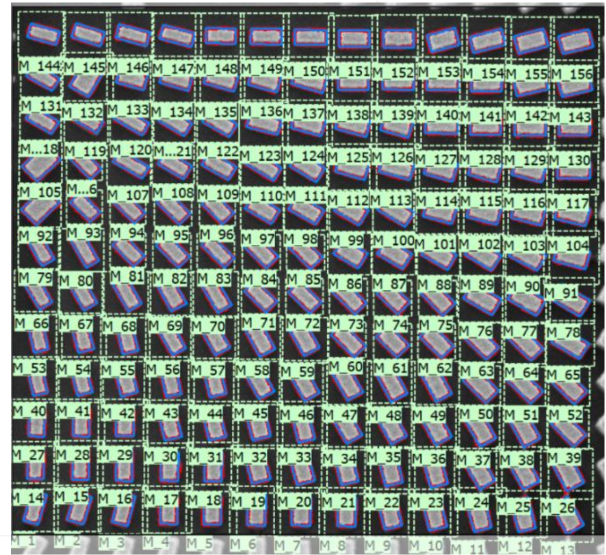
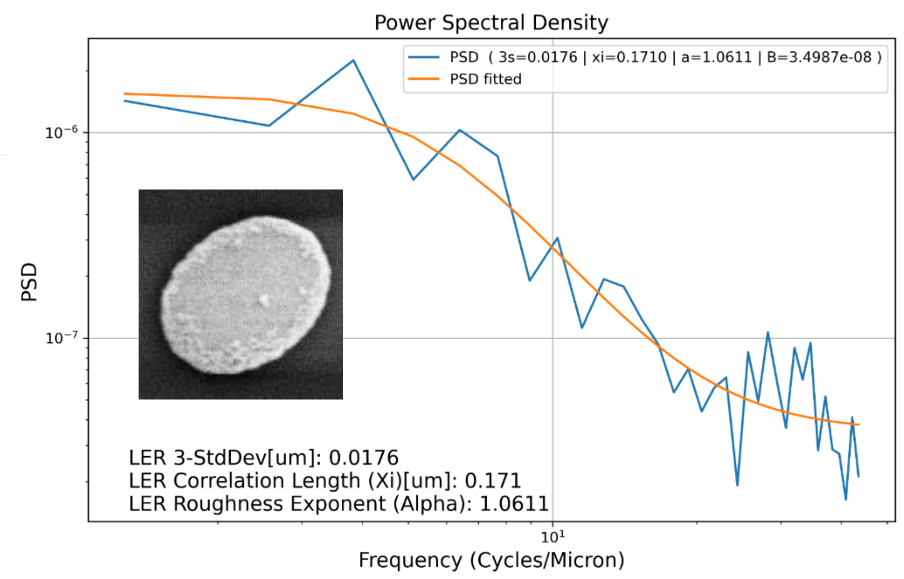
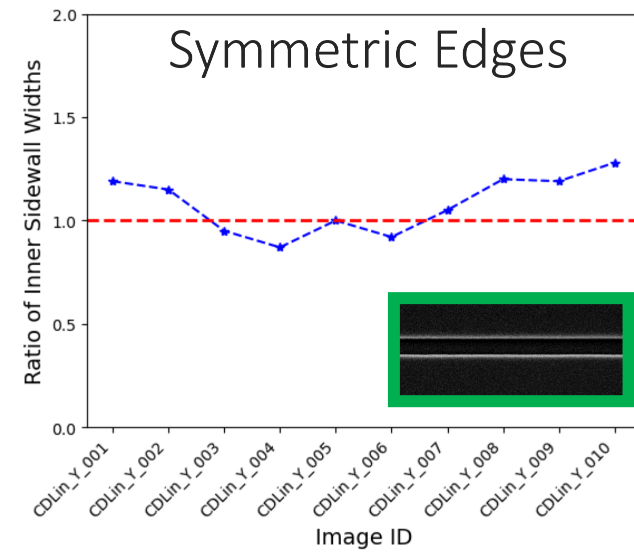
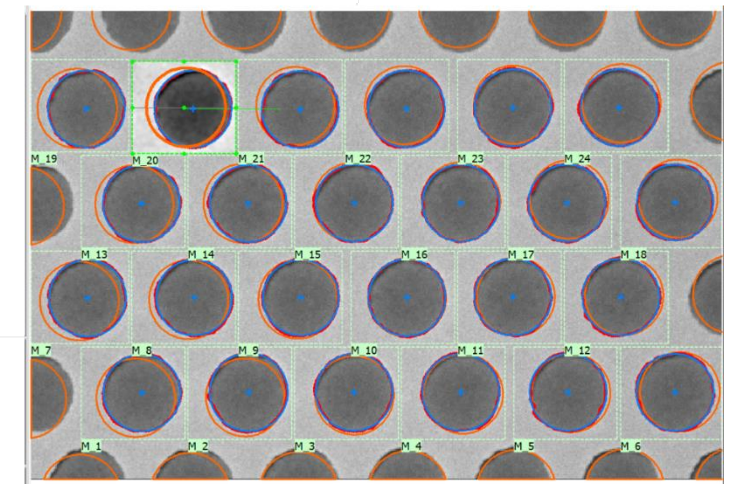
Summary

- Nanostructure image analysis
- Line Edge Roughness
- Side-wall analysis
- Layout-based metrology









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Thank You!

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