Laboratory Scale Star Shade Mask for Testing at Princeton University

Fabrication and Assessment of Petal Edge Accuracy and Defects

Direct Write Device DW#21 Fabrication Completion Date: Dec 26, 2018

Shipped to Princeton University on Jan 25, 2019

Bala K. Balasubramanian, Simon Vuong, Victor White, Karl Yee, Richard Müller

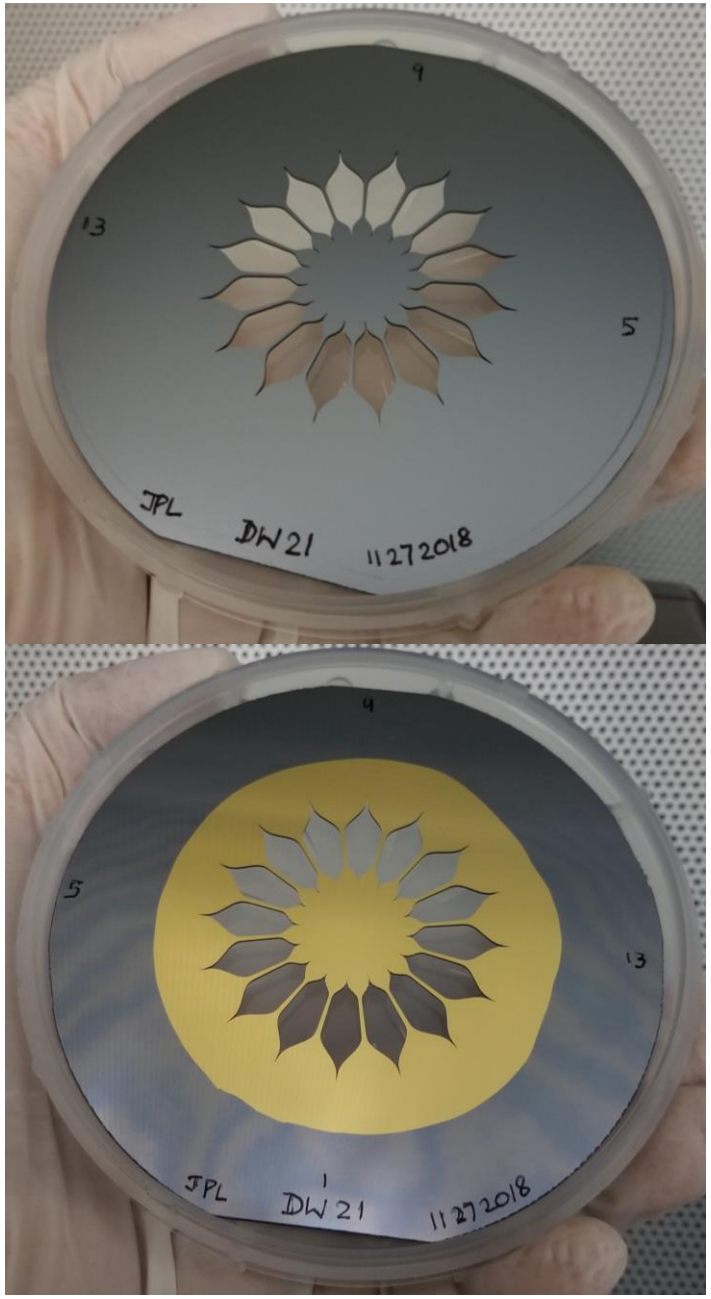
Optics Section 383, Jet Propulsion Laboratory. Jan 25, 2019

Jet Propulsion Laboratory
California Institute of Technology

Starshade Device

Direct Write #21 (DW21)

- Design: Starshade_11_5_18_0.cif
- Device Fab Start Date: Nov 27, 2018
- Device Completion Date: Dec 26, 2018
- Imaging Dates: Dec 2018 – Jan 2019
- Ship Date: 2019-01-25
- Starshade petals are numbered 1-16, with numbers incrementing clockwise about the device when viewed from front (gold coated) side up.

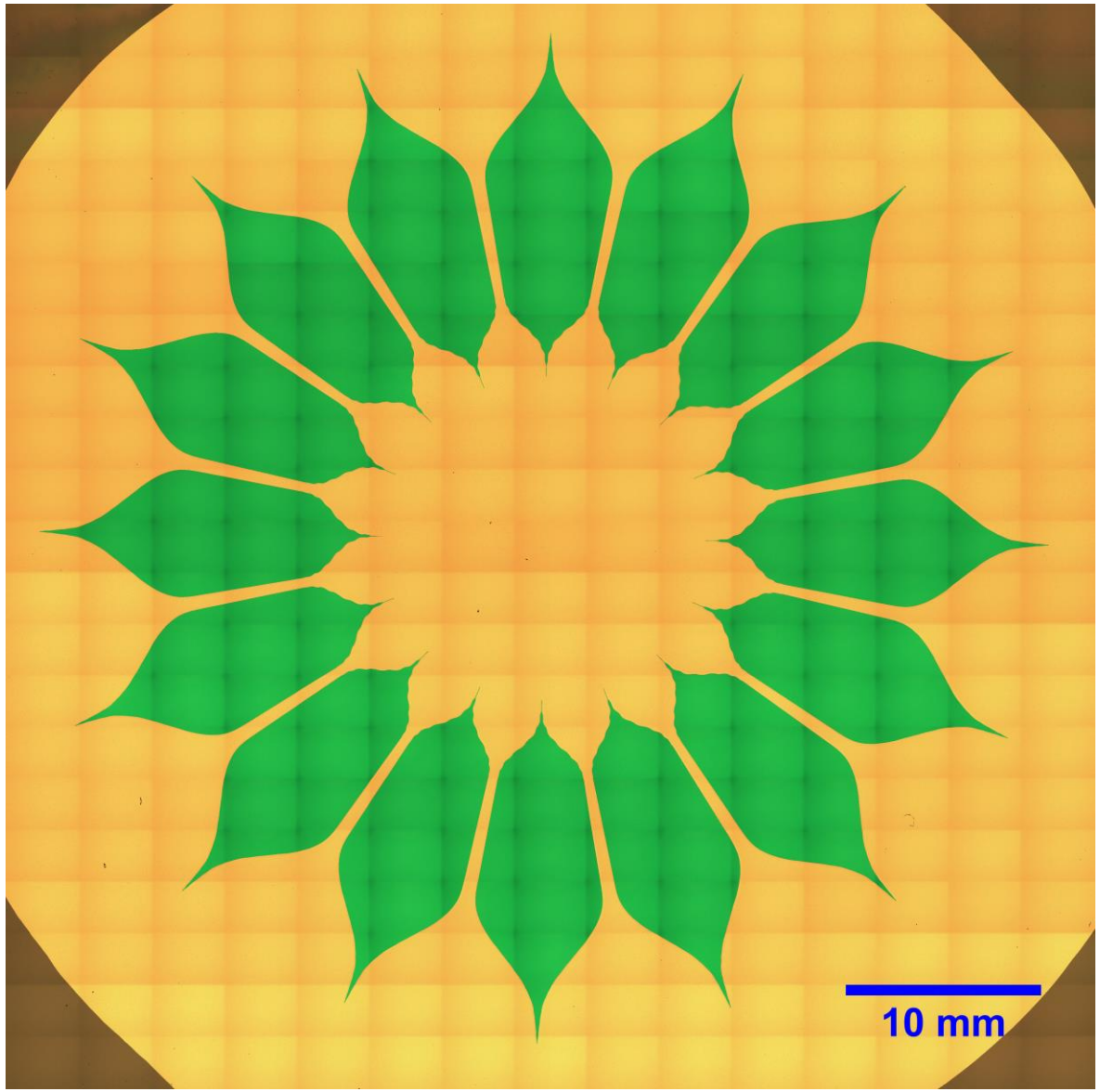


Starshade Device

Direct Write #21 (DW21)

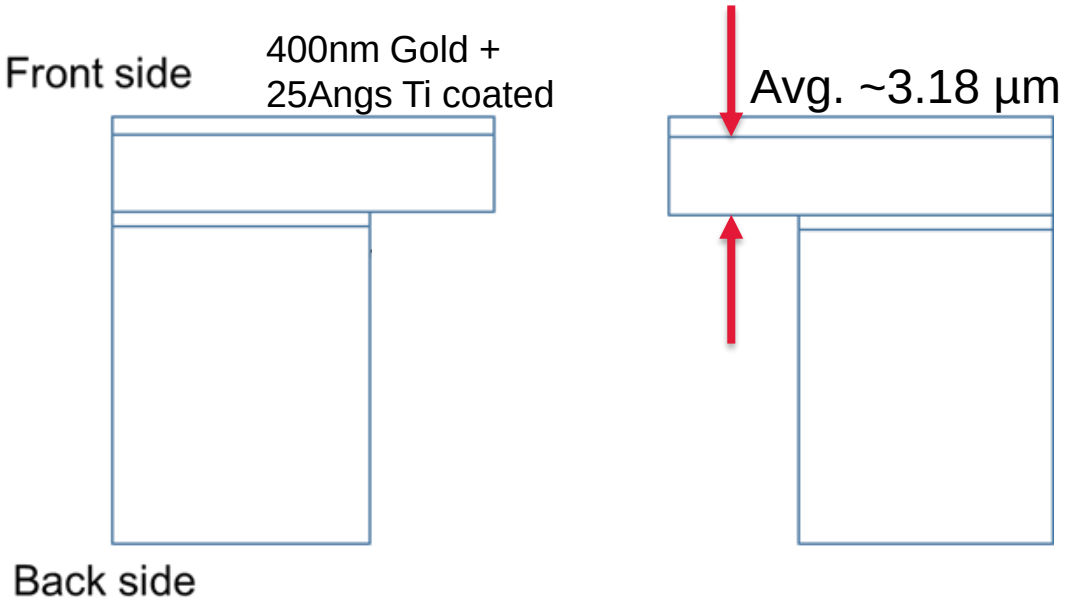
- Full-scan mosaic stitched from 2.5x Transmission and Reflection Objective images.
- File name: **Fullscan_DW21_2.5x_10percentResize** (pixel size: 13.54 µm/pixel after rescaling)

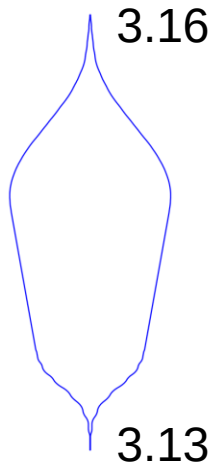
Green Areas : Petal openings in Transmission

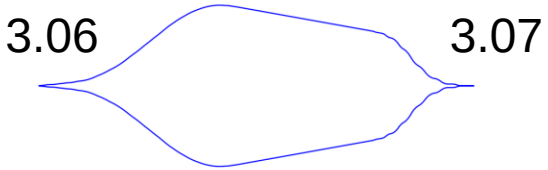


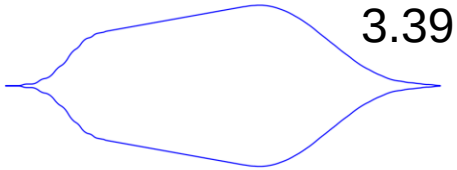
Top Layer Average Thickness

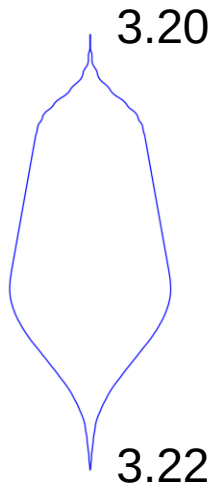
Direct Write #21 (DW21)







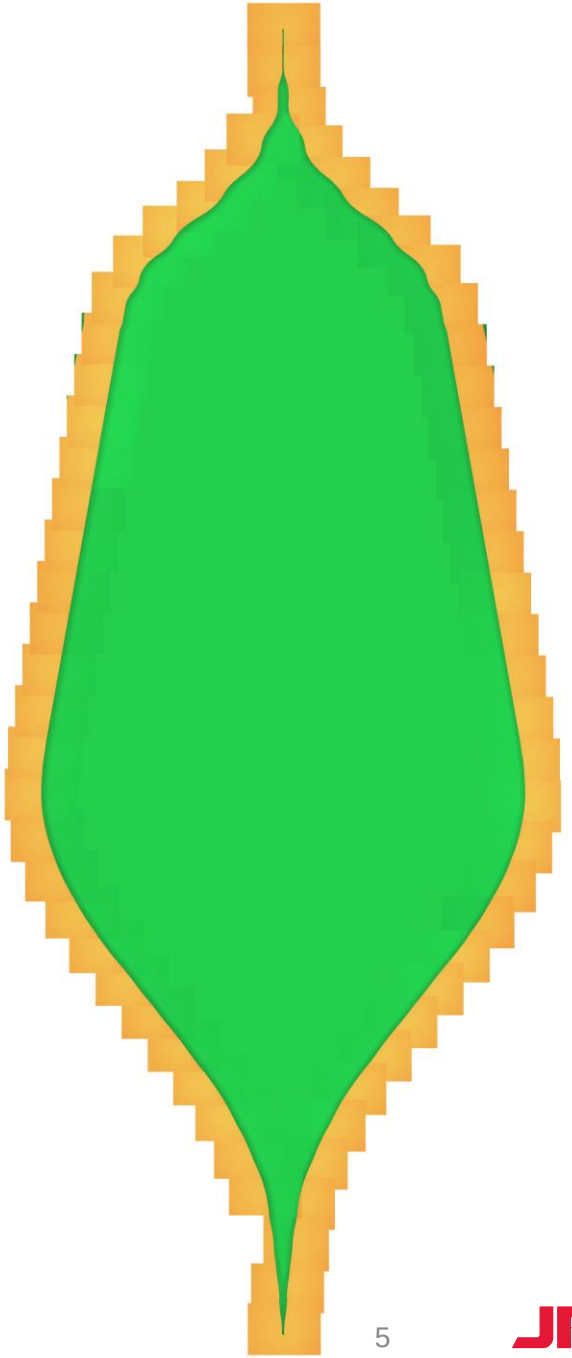




Petal 1

Direct Write #21 (DW21)

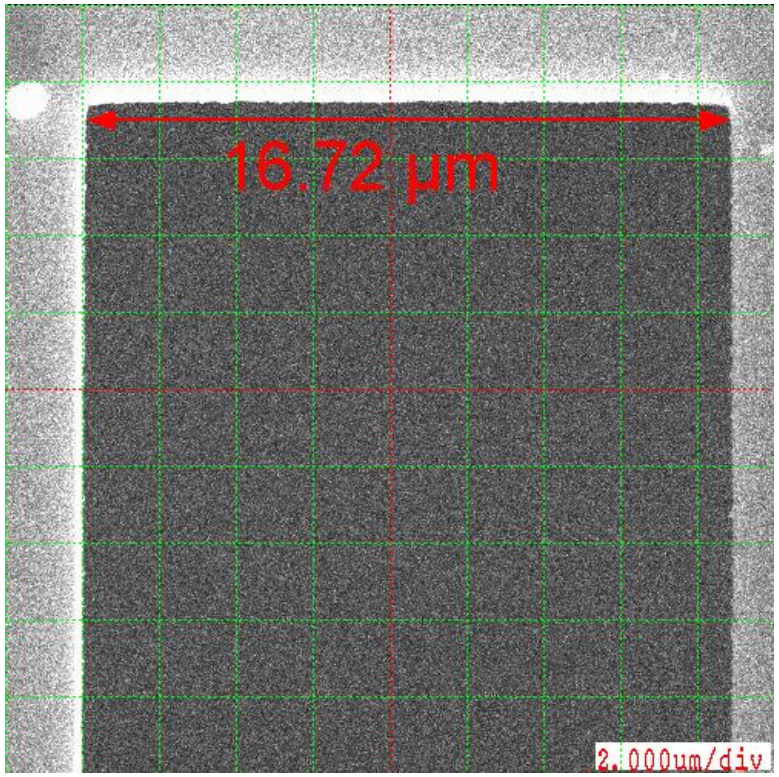
- Series of images taken with 10x Objective in Transmission and Reflection
- Pixel size: 0.34 µm/pixel
- A total of 64 images are taken along the contour of Petal 1 and assembled
- Directory: **…/Individual Microscope Images/Petal 1**
- File format: **20181227_DW21_P1_10xTxRx_****
- Petal 1 tip measurement (next slide)



Green Areas : Petal openings in Transmission

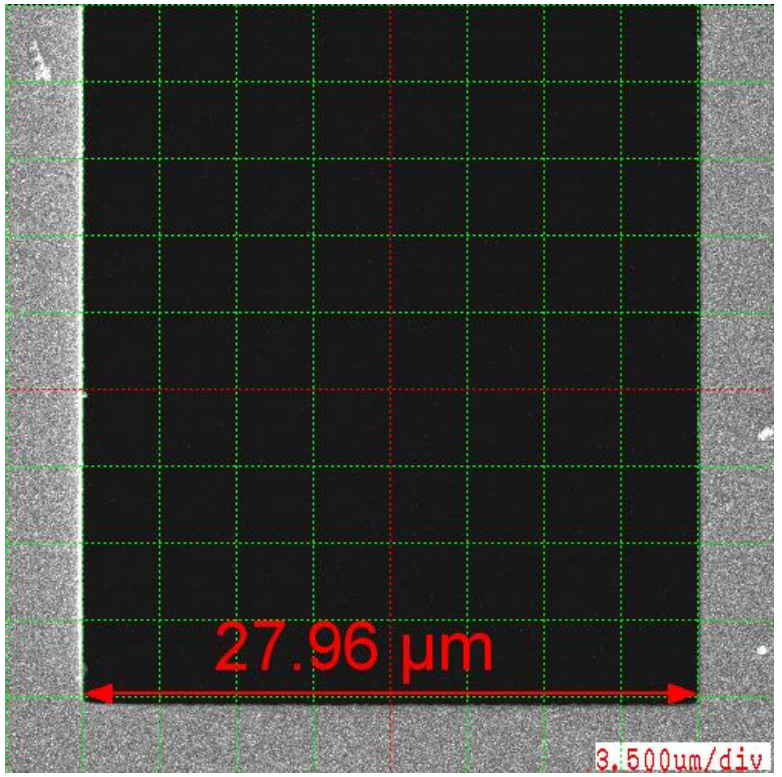
Petal 1 – Tip measurement

Direct Write #21 (DW21)



◀ Inner Tip
Design file spec. = 16.72 µm
RMS edge roughness = 15.6 nm
peak-to-peak edge roughness = 44.3 nm

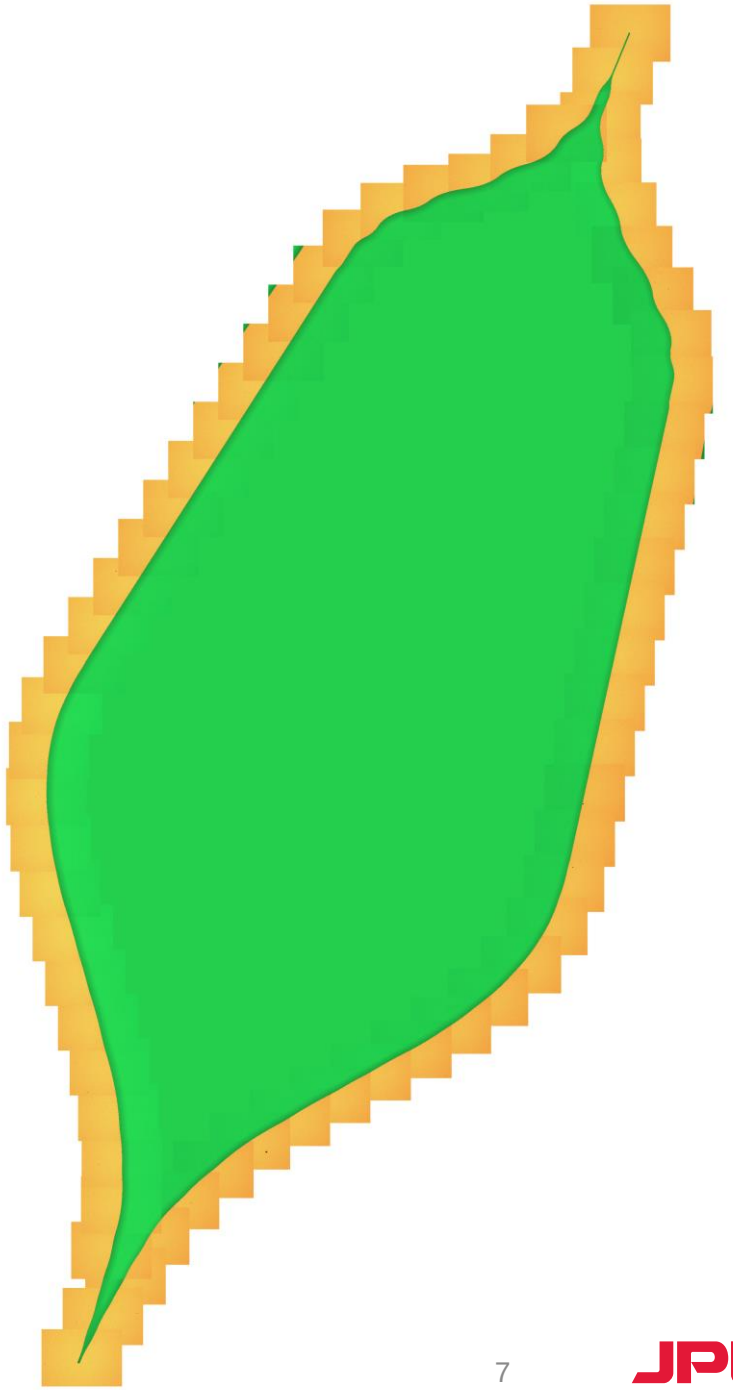
Outer Tip ▶
Design file spec. = 27.85 µm
RMS edge roughness = 8.3 nm
Peak-to-peak edge roughness = 70 nm



Petal 2

Direct Write #21 (DW21)

- Series of images taken with 10x Objective in Transmission and Reflection
- Pixel size: 0.34 µm/pixel
- A total of 65 images are taken along the contour of Petal 2 and assembled
- Directory: **…/Individual Microscope Images/Petal 2**
- File format: **20181227_DW21_P2_10xTxRx_****

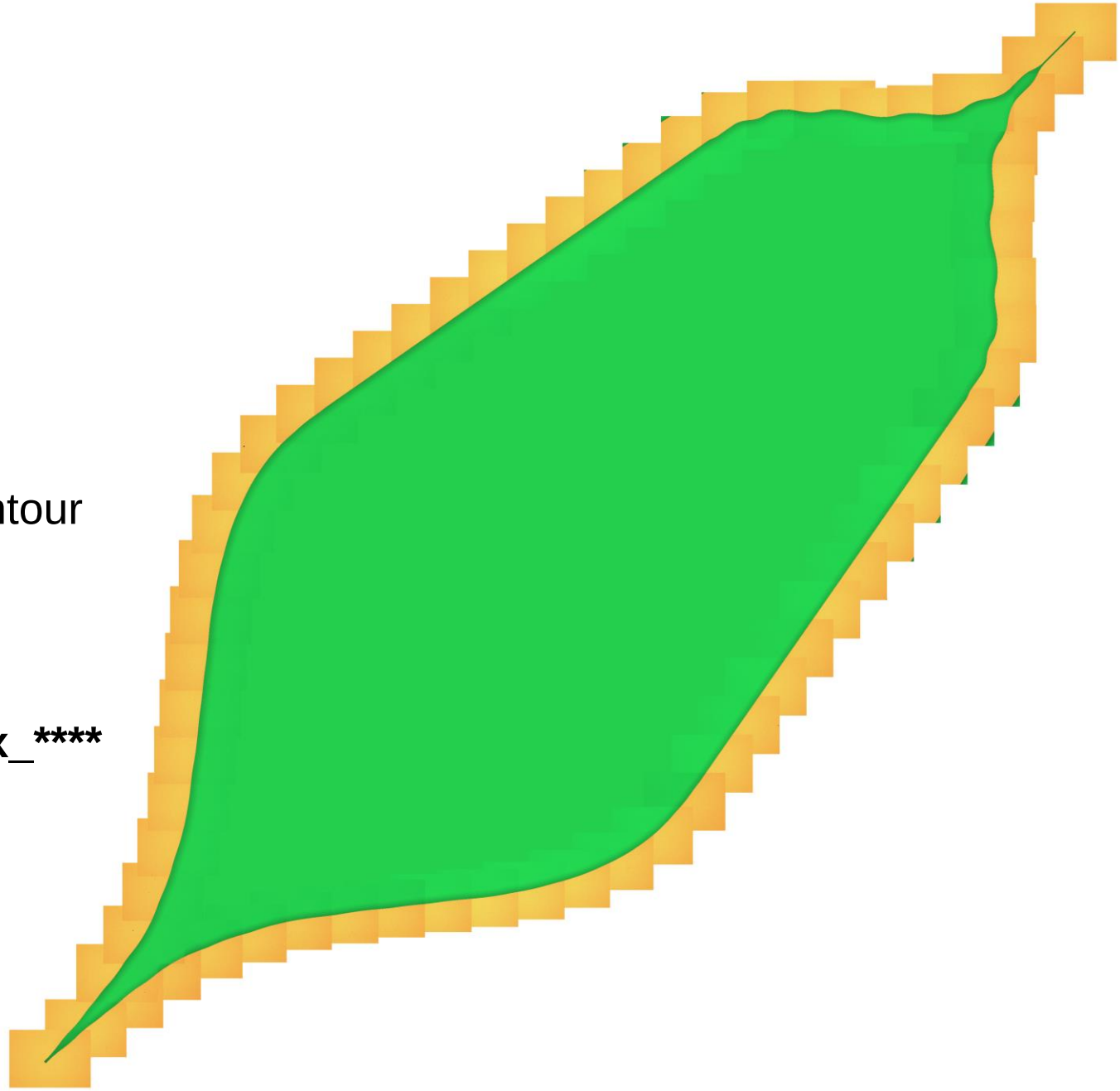


Green Areas : Petal openings in Transmission

Petal 3

Direct Write #21 (DW21)

- Series of images taken with 10x objective in Transmission and Reflection
- Pixel size: 0.34 µm/pixel
- A total of 65 images are taken along the contour of Petal 3 and assembled
- Directory: **…/Individual Microscope Images/Petal 3**
- File format: **20181227_DW21_P3_10xTxRx_****

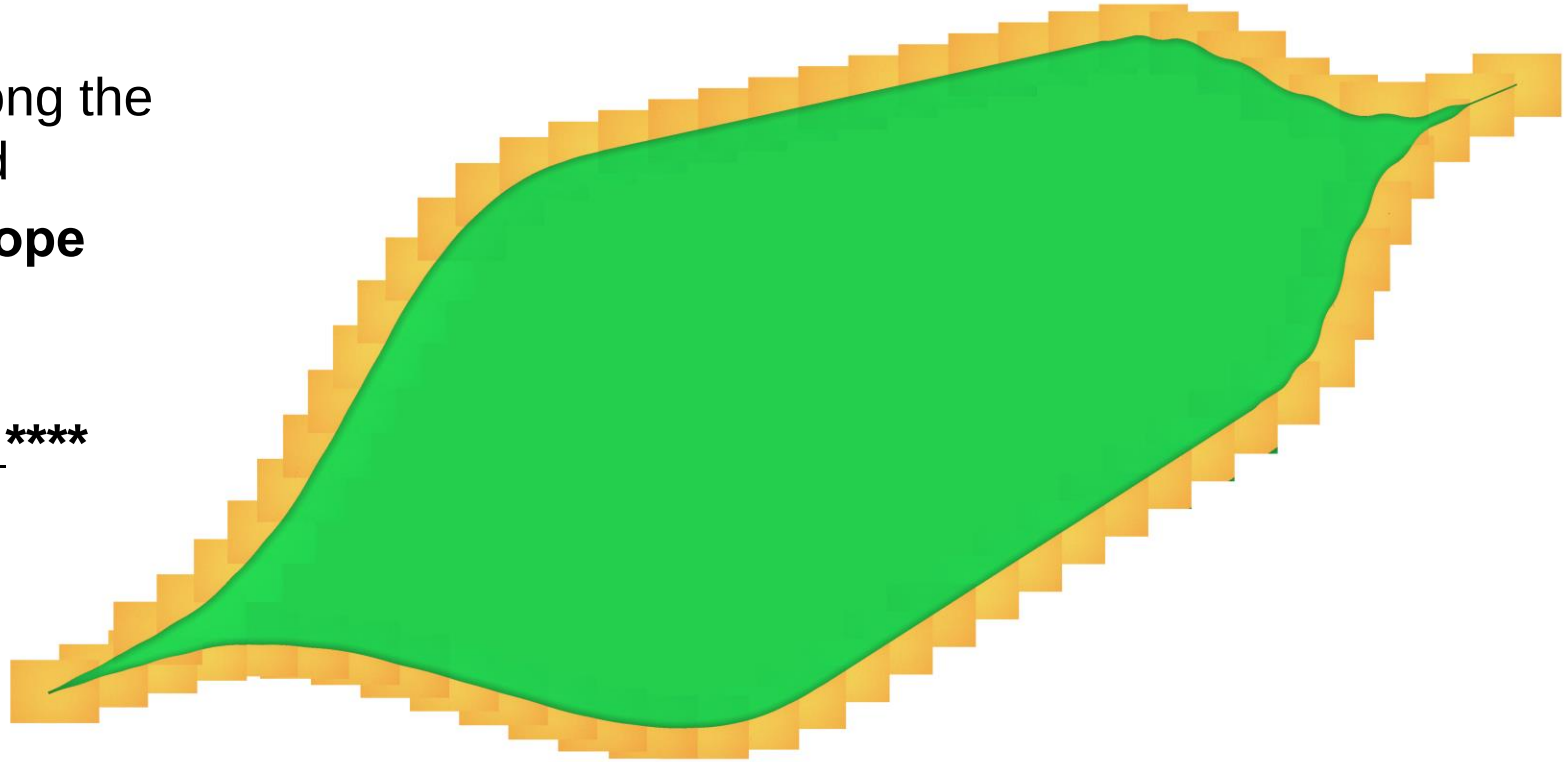


Green Areas : Petal openings in Transmission

Petal 4

Direct Write #21 (DW21)

- Series of images taken with 10x Objective in Transmission and Reflection
- Pixel size: 0.34 µm/pixel
- A total of 65 images are taken along the contour of Petal 4 and assembled
- Directory: **…/Individual Microscope Images/Petal 4**
- File format: **20181227_DW21_P4_10xTxRx_****



Green Areas : Petal openings in Transmission

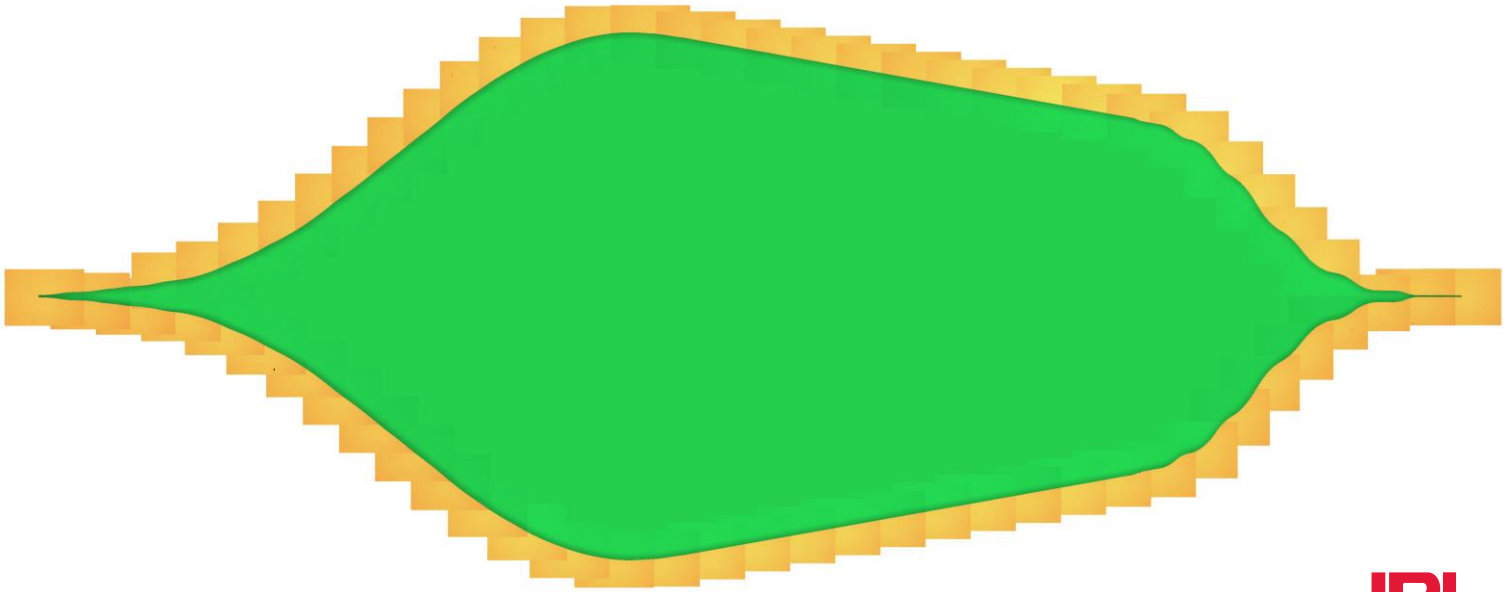
Petal 5

Direct Write #21 (DW21)

- Series of images taken with 10x Objective in Transmission and Reflection
- Pixel size: 0.34 µm/pixel
- A total of 64 images are taken along the contour of Petal 5 and assembled
- Petal 5 tip measurement

  (next slide)

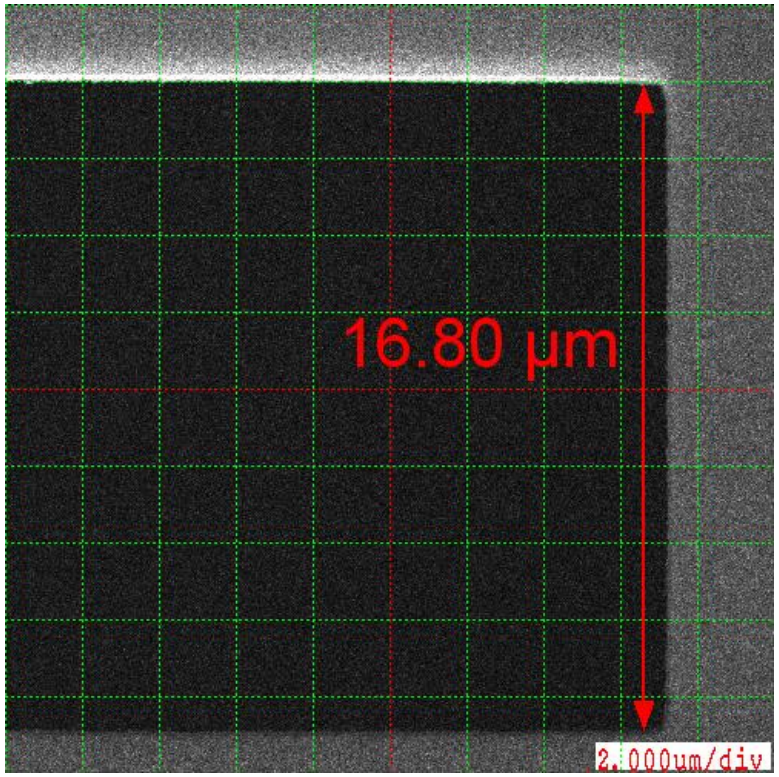
- Directory: **…/Individual Microscope Images/Petal 5**
- File format: **20181227_DW21_P5_10xTxRx_****



Green Areas : Petal openings in Transmission

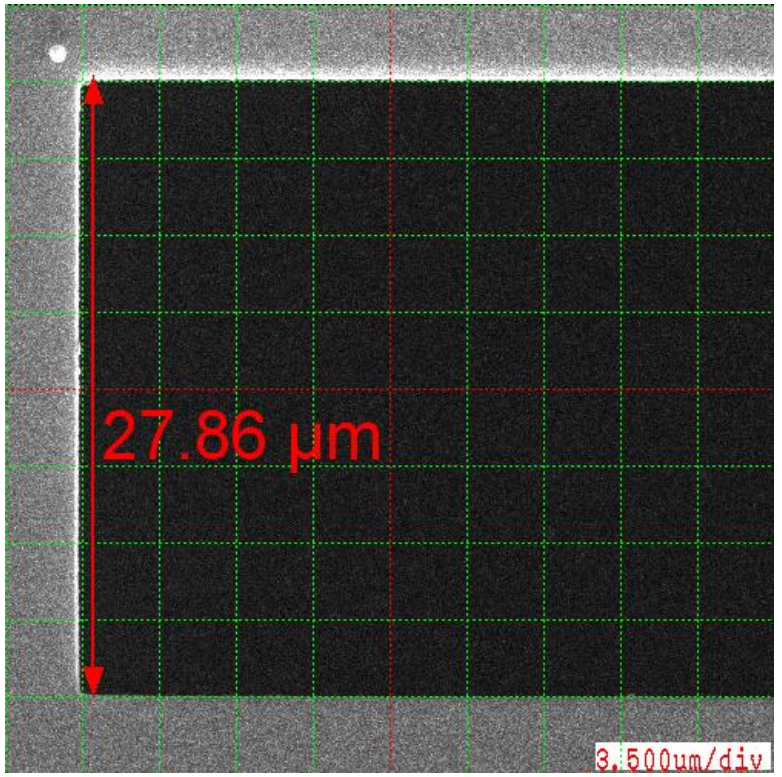
Petal 5 – Tip measurement

Direct Write #21 (DW21)



◀ Inner Tip
Design file spec. = 16.72 µm
RMS edge roughness = 16.1 nm
Peak-to-peak edge roughness = 77.5 nm

Outer Tip ▶
Design file spec. = 27.85 µm
RMS edge roughness = 19 nm
Peak-to-peak edge roughness = 71.5 nm

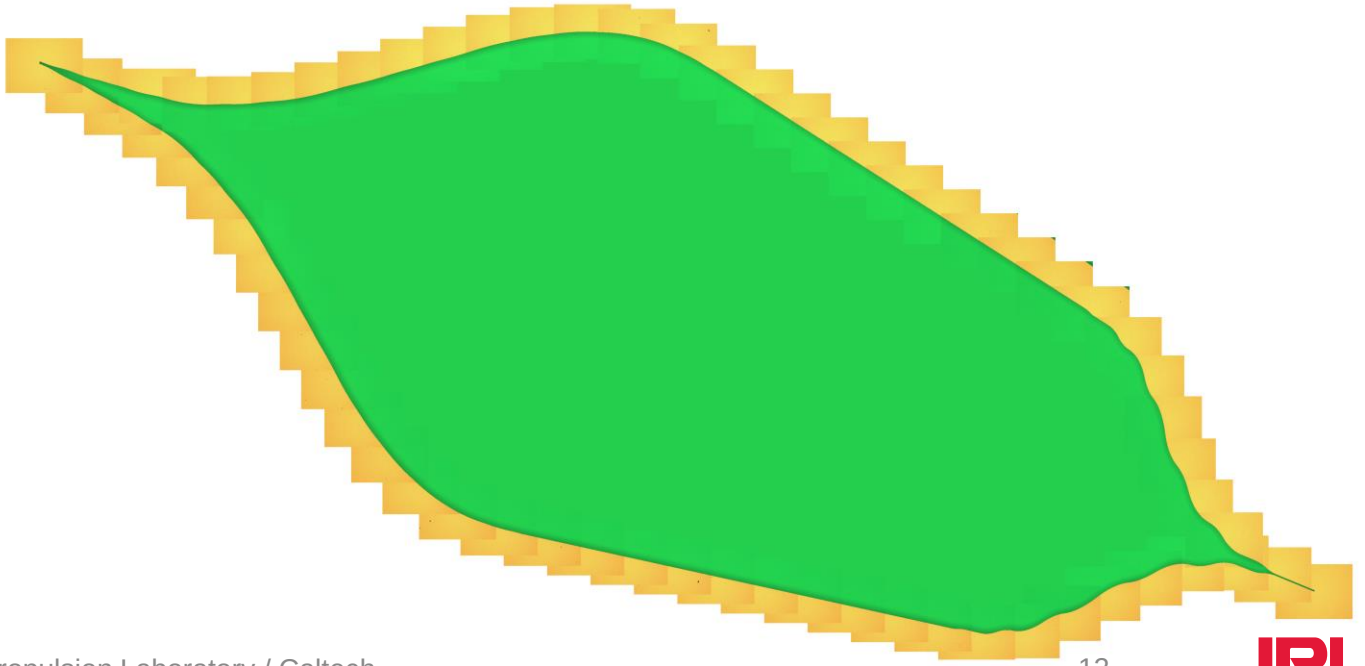


Petal 6

Direct Write #21 (DW21)

- Series of images taken with 10x Objective in Transmission and Reflection
- A total of 65 images are taken along the contour of Petal 6 and assembled

- Directory: **…/Individual Microscope Images/Petal 6**
- File format: **20181227_DW21_P6_10xTxRx_****

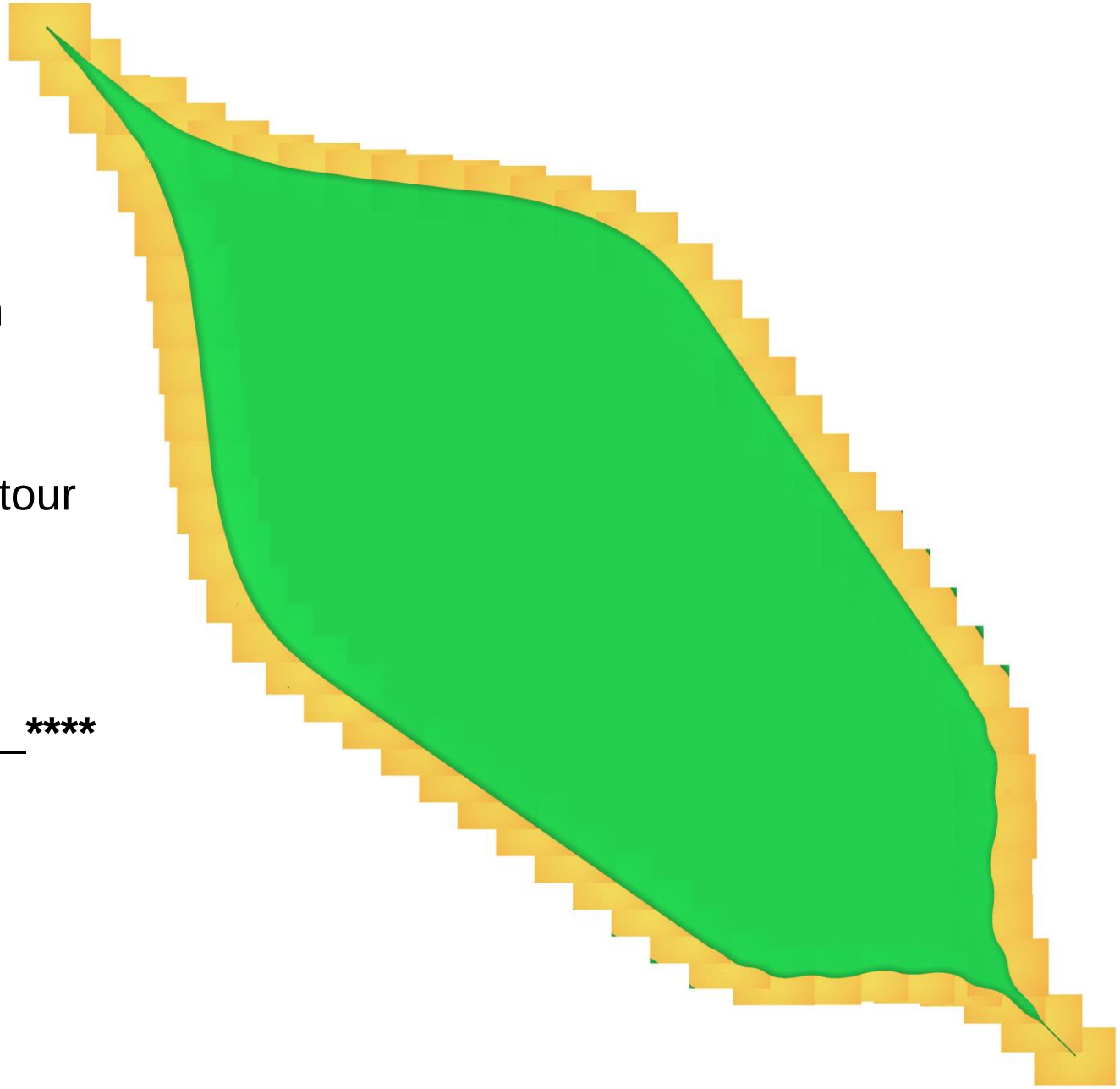


Green Areas : Petal openings in Transmission

Petal 7

Direct Write #21 (DW21)

- Series of images taken with 10x Objective in Transmission and Reflection
- Pixel size: 0.34 µm/pixel
- A total of 65 images are taken along the contour of Petal 7 and assembled
- Directory: **…/Individual Microscope Images/Petal 7**
- File format: **20181227_DW21_P7_10xTxRx_****

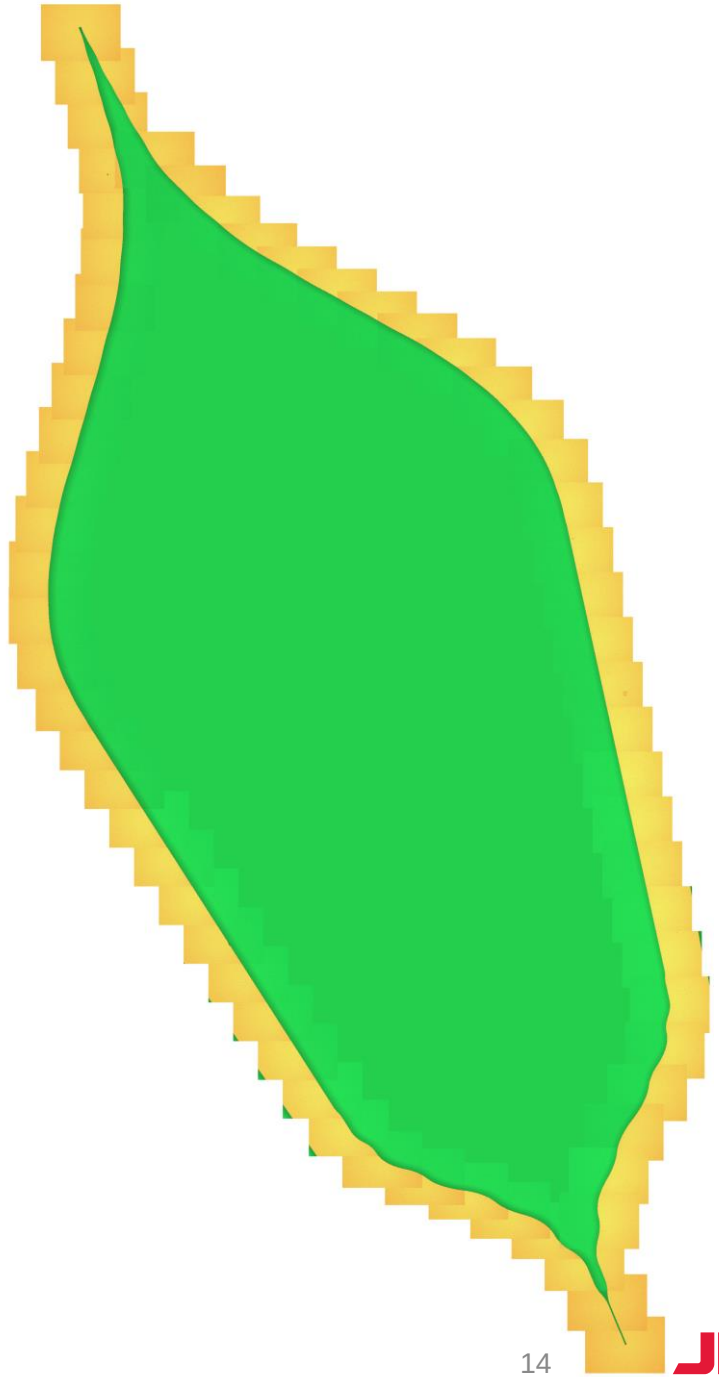


Green Areas : Petal openings in Transmission

Petal 8

Direct Write #21 (DW21)

- Series of images taken with 10x Objective in Transmission and Reflection
- Pixel size: 0.34 µm/pixel
- A total of 64 images are taken along the contour of Petal 8 and assembled
- Directory: **…/Individual Microscope Images/Petal 8**
- File format: **20181227_DW21_P8_10xTxRx_****



Green Areas : Petal openings in Transmission

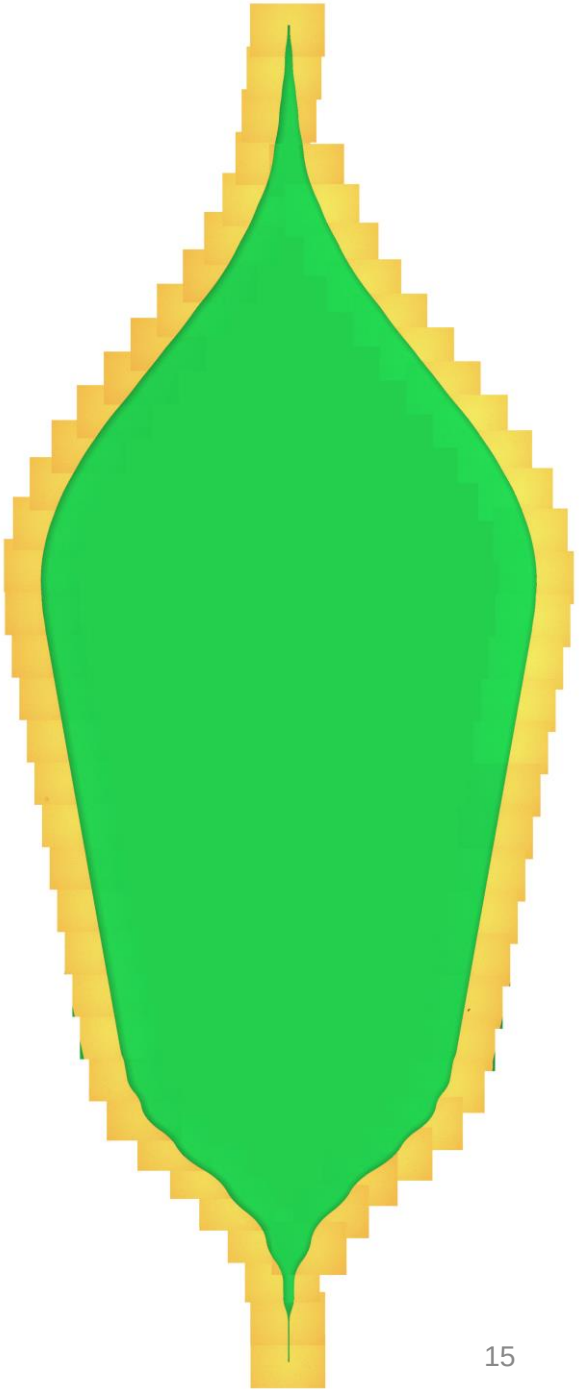
Petal 9

Direct Write #21 (DW21)

- Series of images taken with 10x Objective in Transmission and Reflection
- Pixel size: 0.34 µm/pixel
- A total of 64 images are taken along the contour of Petal 9 and assembled
- Directory: **…/Individual Microscope Images/Petal 9**
- File format: **20181227_DW21_P9_10xTxRx_****** (see figure for number legend)
- Petal 9 tip measurement

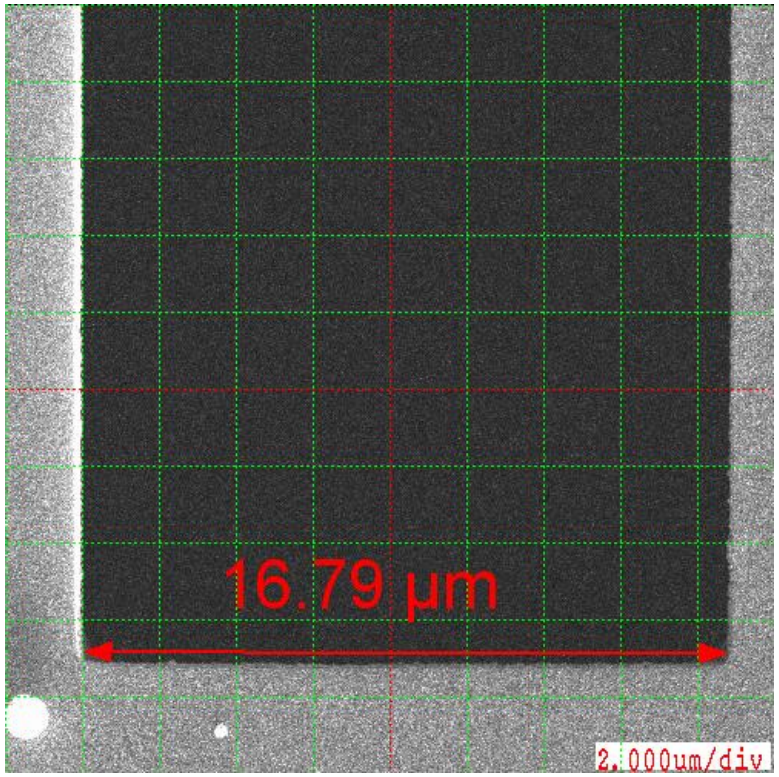
(next slide)

Green Areas : Petal openings in Transmission



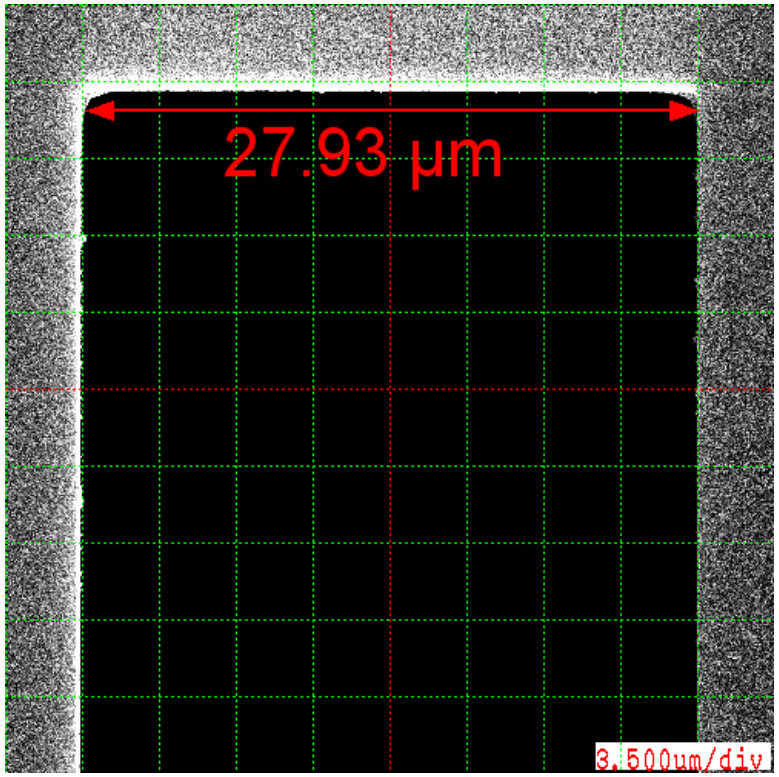
Petal 9 – Tip measurement

Direct Write #21 (DW21)



◀ Inner Tip
RMS edge roughness = 19.1 nm
Peak-to-peak edge roughness = 88.5 nm
Design file spec. = 16.72 µm

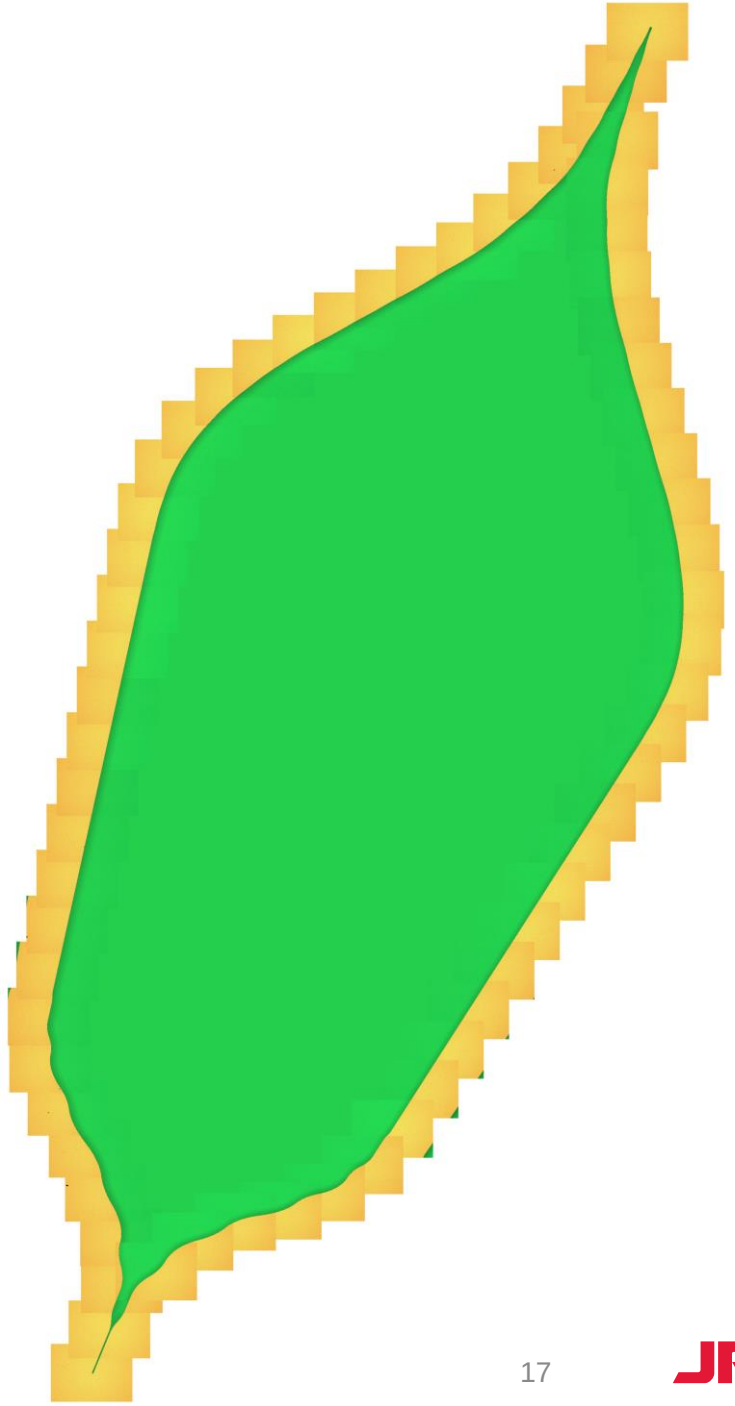
Outer Tip ▶
RMS edge roughness = 37.9 nm
Peak-to-peak edge roughness = 0.14 µm
Design file spec. = 27.85 µm



Petal 10

Direct Write #21 (DW21)

- Series of images taken with 10x Objective in Transmission and Reflection
- Pixel size: 0.34 µm/pixel
- A total of 65 images are taken along the contour of Petal 10 and assembled
- Directory: **…/Individual Microscope Images/Petal 10**
- File format: **20181227_DW21_P10_10xTxRx_****** (see figure for number legend)

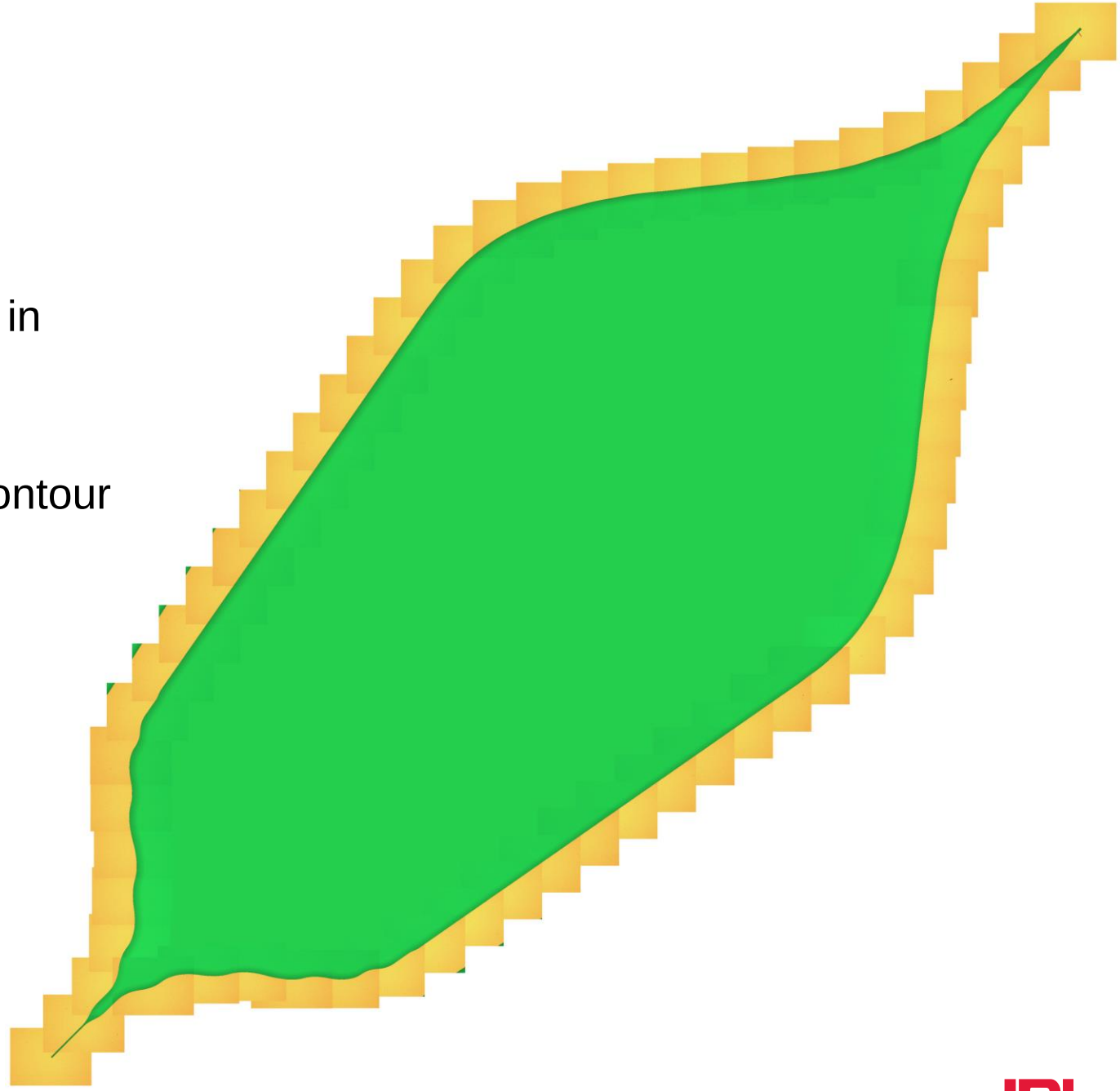


Green Areas : Petal openings in Transmission

Petal 11

Direct Write #21 (DW21)

- Series of images taken with 10x Objective in Transmission and Reflection
- Pixel size: 0.34 µm/pixel
- A total of 65 images are taken along the contour of Petal 11 and assembled
- Directory: **…/Individual Microscope Images/Petal 11**
- File format: **20181227_DW21_P11_10xTxRx_****



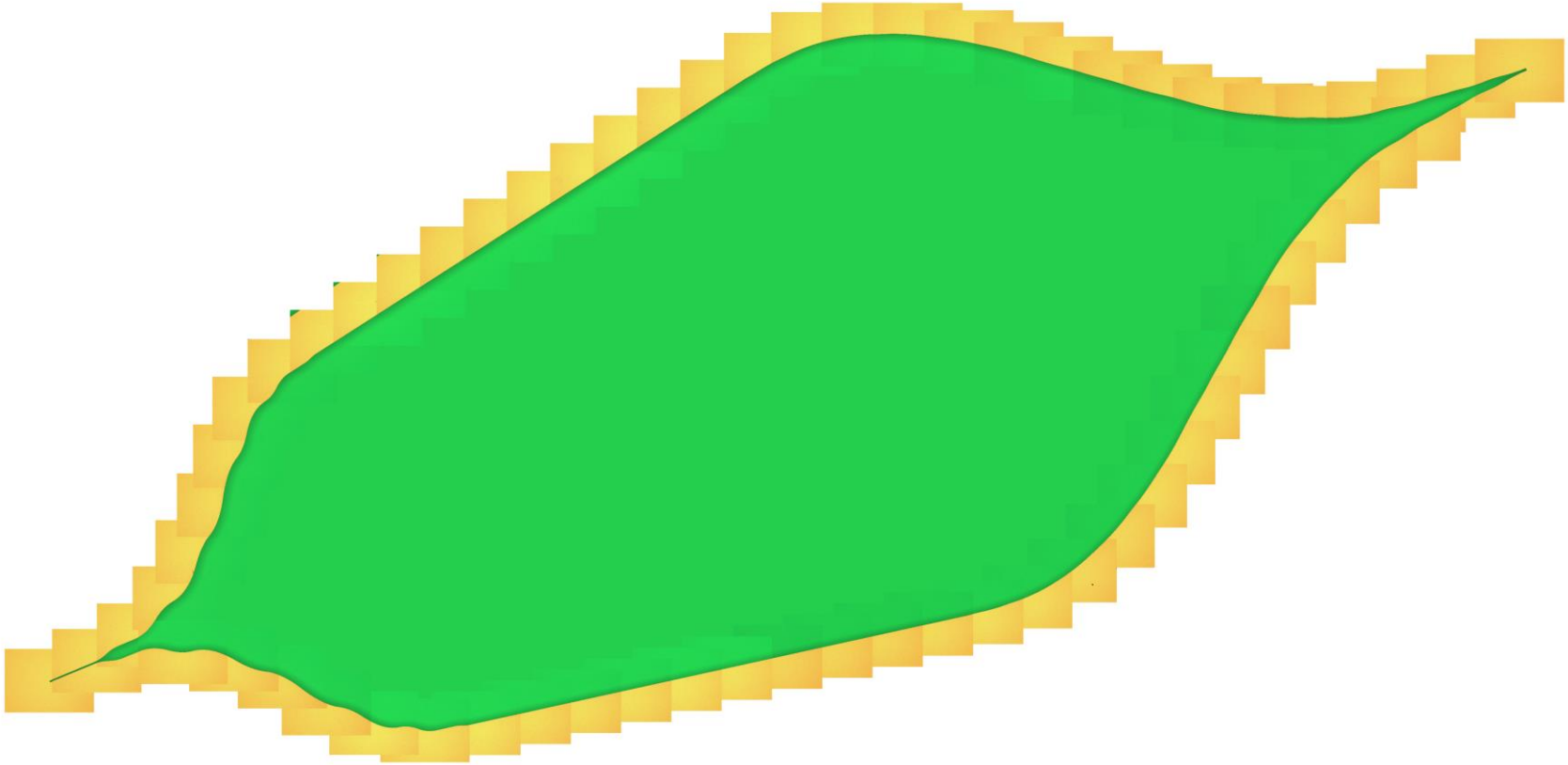
Green Areas : Petal openings in Transmission

Petal 12

Direct Write #21 (DW21)

- Series of images taken with 10x Objective in Transmission and Reflection
- Pixel size: 0.34 µm/pixel
- A total of 65 images are taken along the contour of Petal 12 and assembled

- Directory: **…/Individual Microscope Images/Petal 12**
- File format: **20181227_DW21_P12_10xTxRx_****



Green Areas : Petal openings in Transmission

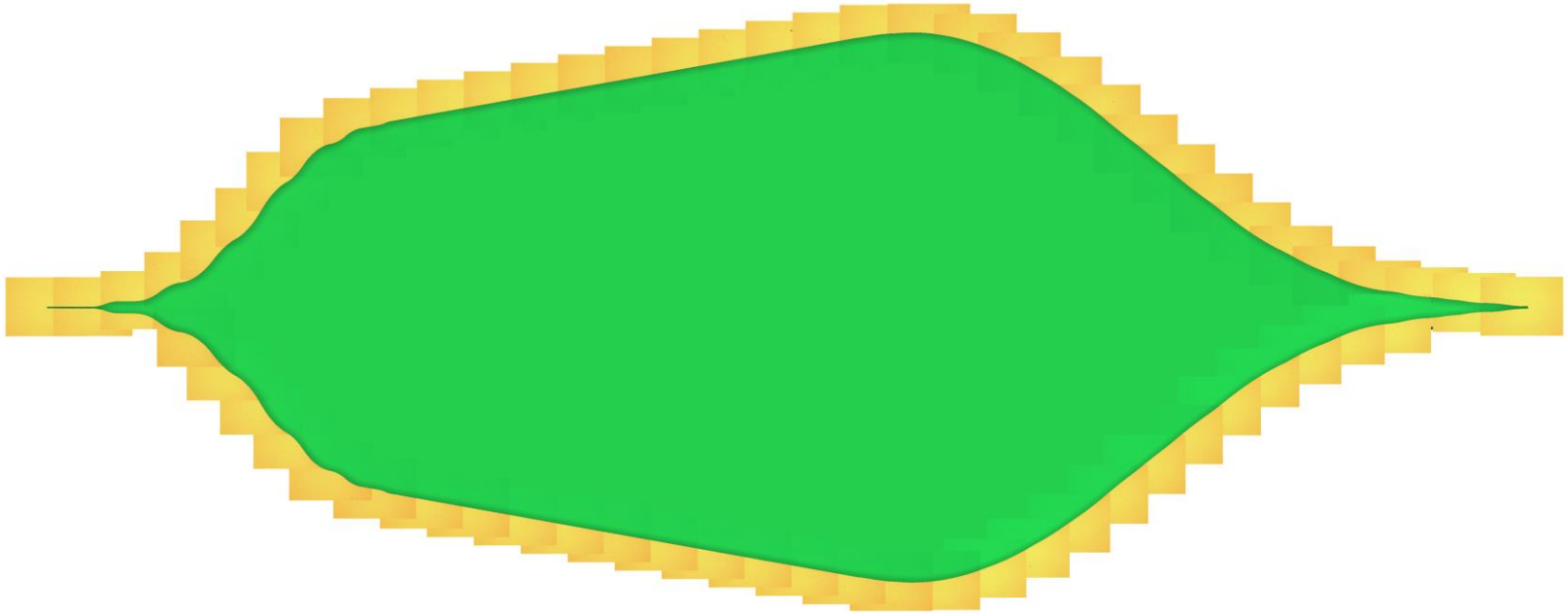
Petal 13

Direct Write #21 (DW21)

- Series of images taken with 10x Objective in Transmission and Reflection
- Pixel size: 0.34 µm/pixel
- A total of 64 images are taken along the contour of Petal 13 and assembled
- Petal 13 tip measurement

(next slide)

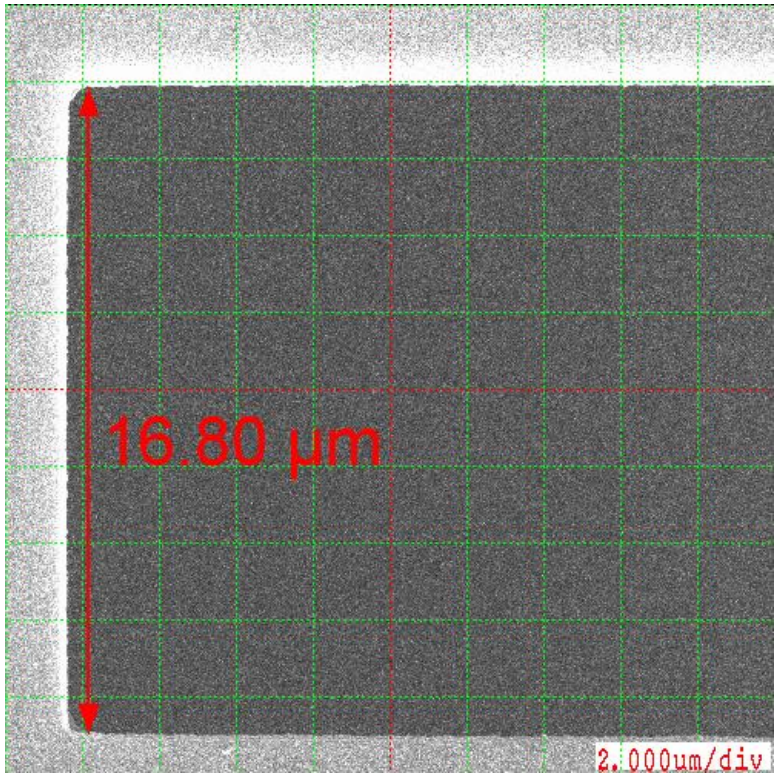
- Directory: **…/Individual Microscope Images/Petal 13**
- File format: **20181227_DW21_P13_10xTxRx_****



Green Areas : Petal openings in Transmission

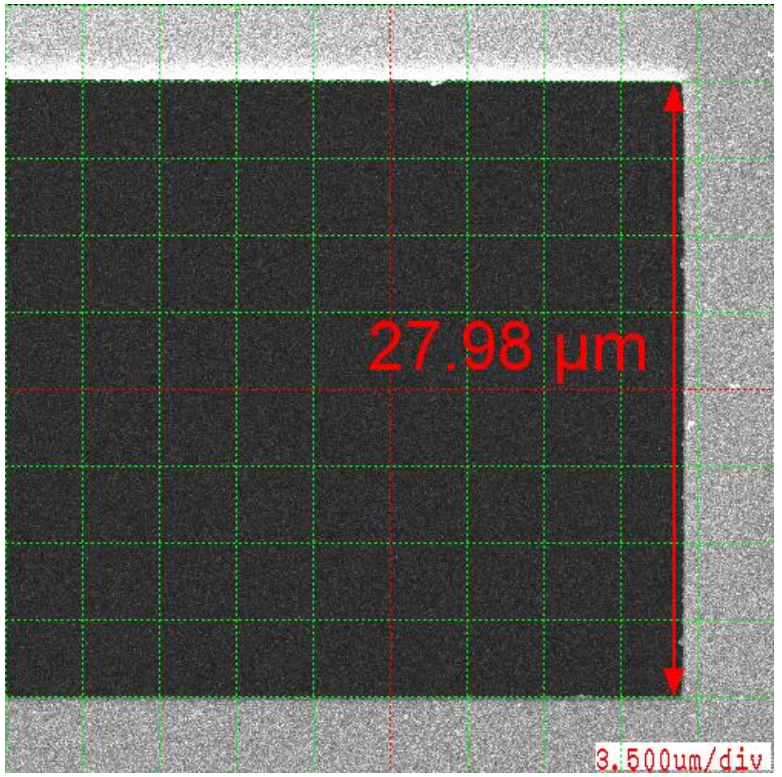
Petal 13 – Tip measurement

Direct Write #21 (DW21)



◀ Inner Tip
RMS edge roughness = 19.2 nm
Peak-to-peak edge roughness = 74.5 nm
Design file spec. = 16.72 µm

Outer Tip ▶
RMS edge roughness = 30.5 nm
Peak-to-peak edge roughness = 0.10 µm
Design file spec. = 27.85 µm

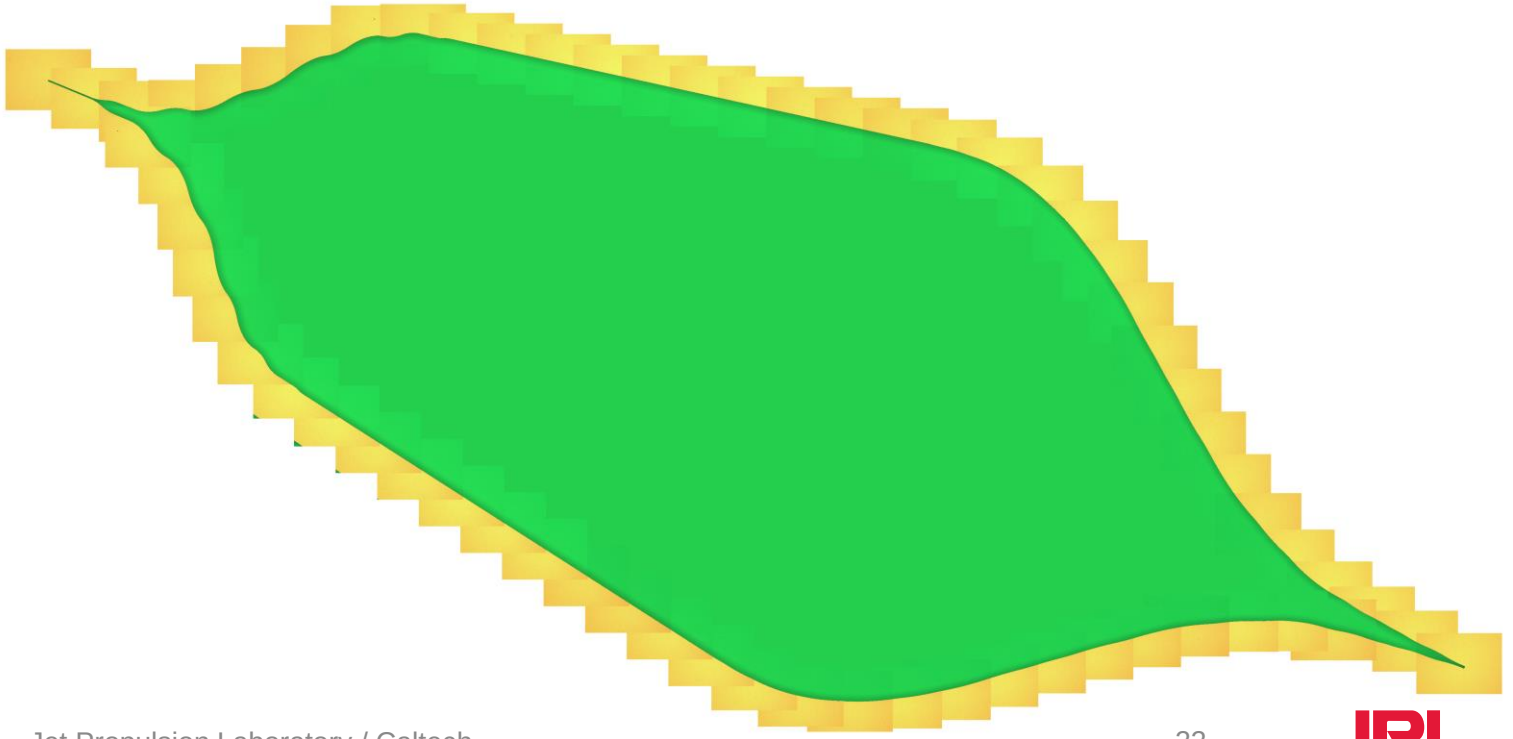


Petal 14

Direct Write #21 (DW21)

- Series of images taken with 10x Objective in Transmission and Reflection
- Pixel size: 0.34 µm/pixel
- A total of 65 images are taken along the contour of Petal 14 and assembled

- Directory: **…/Individual Microscope Images/Petal 14**
- File format: **20181227_DW21_P14_10xTxRx_****

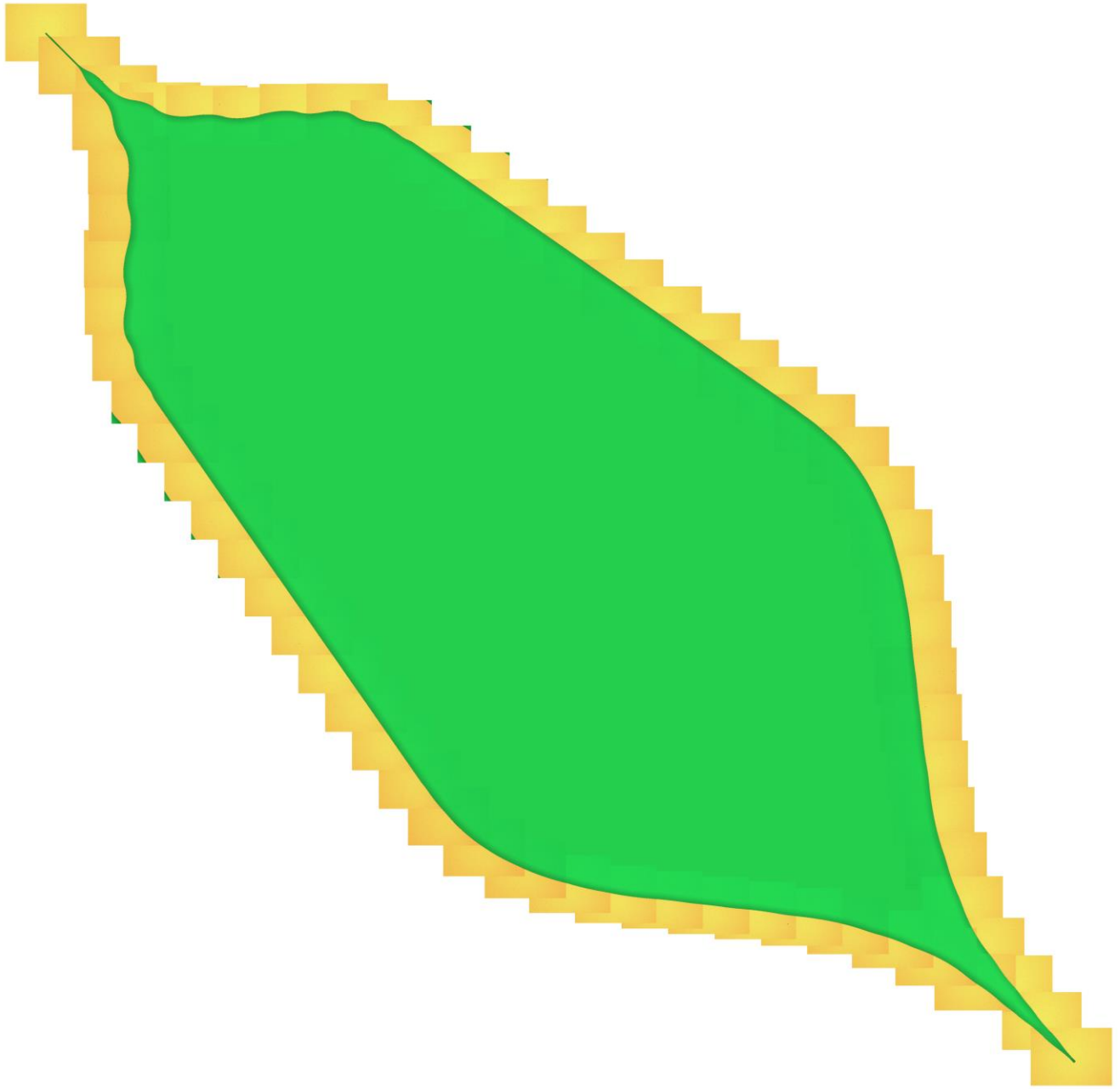


Green Areas : Petal openings in Transmission

Petal 15

Direct Write #21 (DW21)

- Series of images taken with 10x Objective in Transmission and Reflection
- Pixel size: 0.34 µm/pixel
- A total of 65 images are taken along the contour of Petal 15 and assembled
- Directory: **…/Individual Microscope Images/Petal 15**
- File format: **20181227_DW21_P15_10xTxRx_****

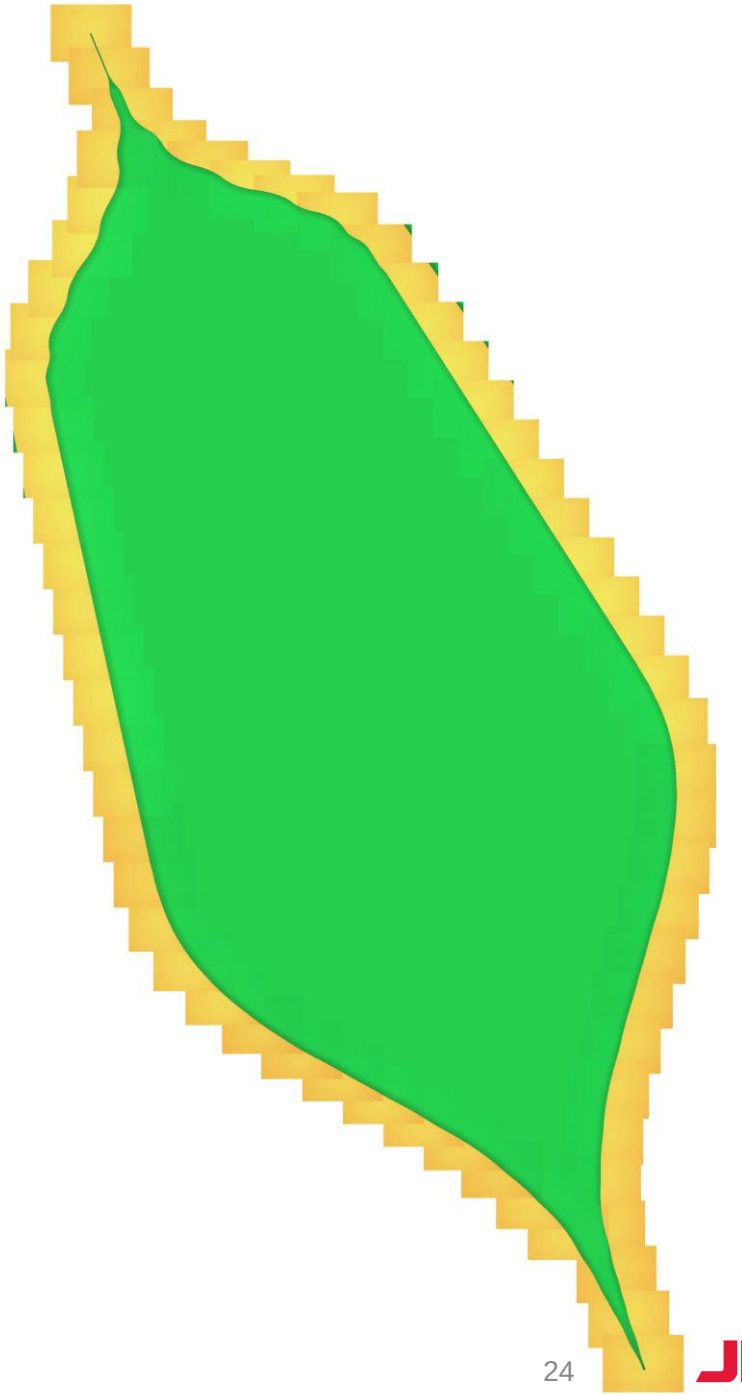


Green Areas : Petal openings in Transmission

Petal 16

Direct Write #21 (DW21)

- Series of images taken with 10x Objective in Transmission and Reflection
- Pixel size: 0.34 µm/pixel
- A total of 64 images are taken along the contour of Petal 16 and assembled
- Directory: **…/Individual Microscope Images/Petal 16**
- File format: **20181227_DW21_P16_10xTxRx_****

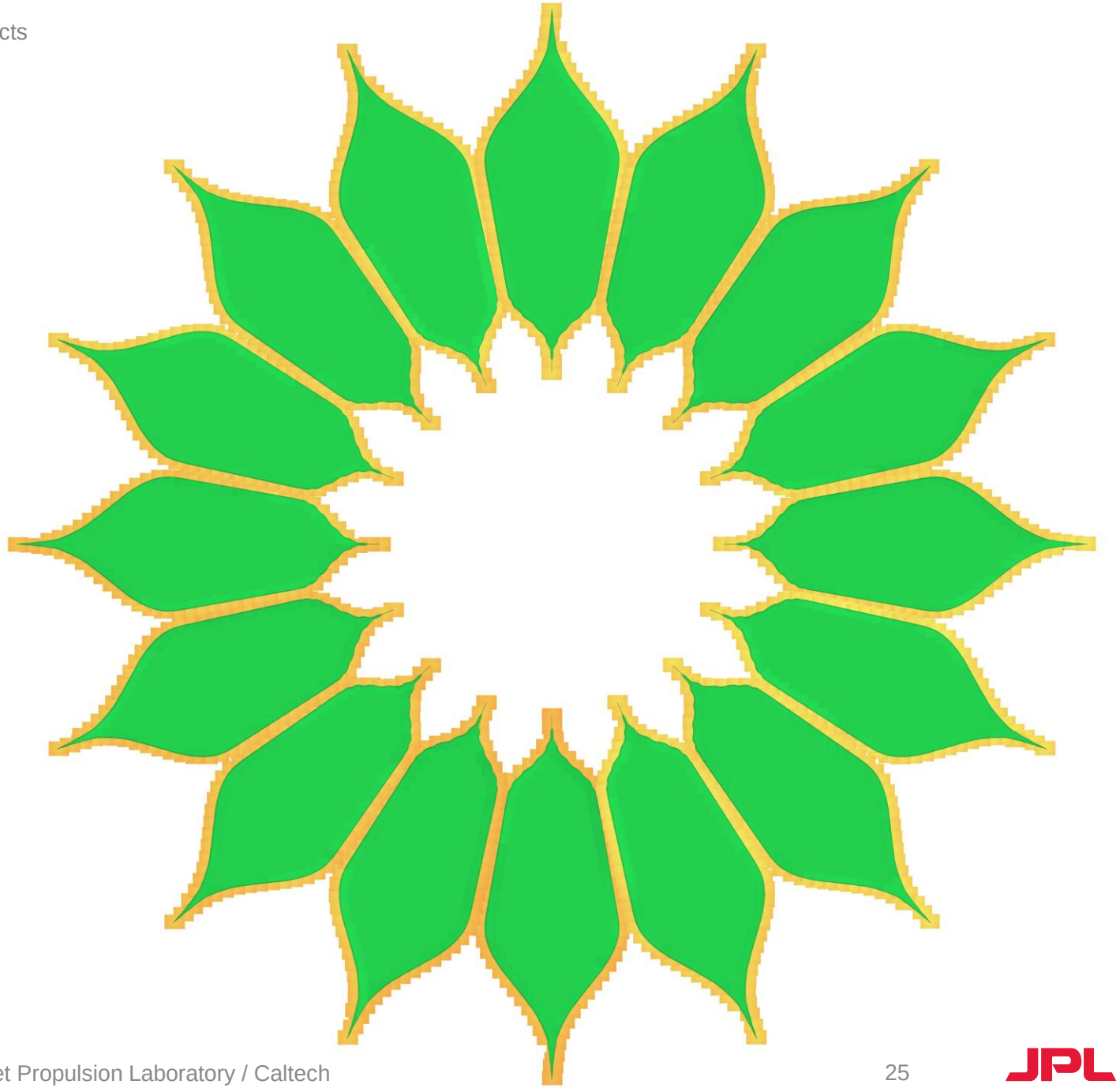


Green Areas : Petal openings in Transmission

Starshade Device

Direct Write #21 (DW21)

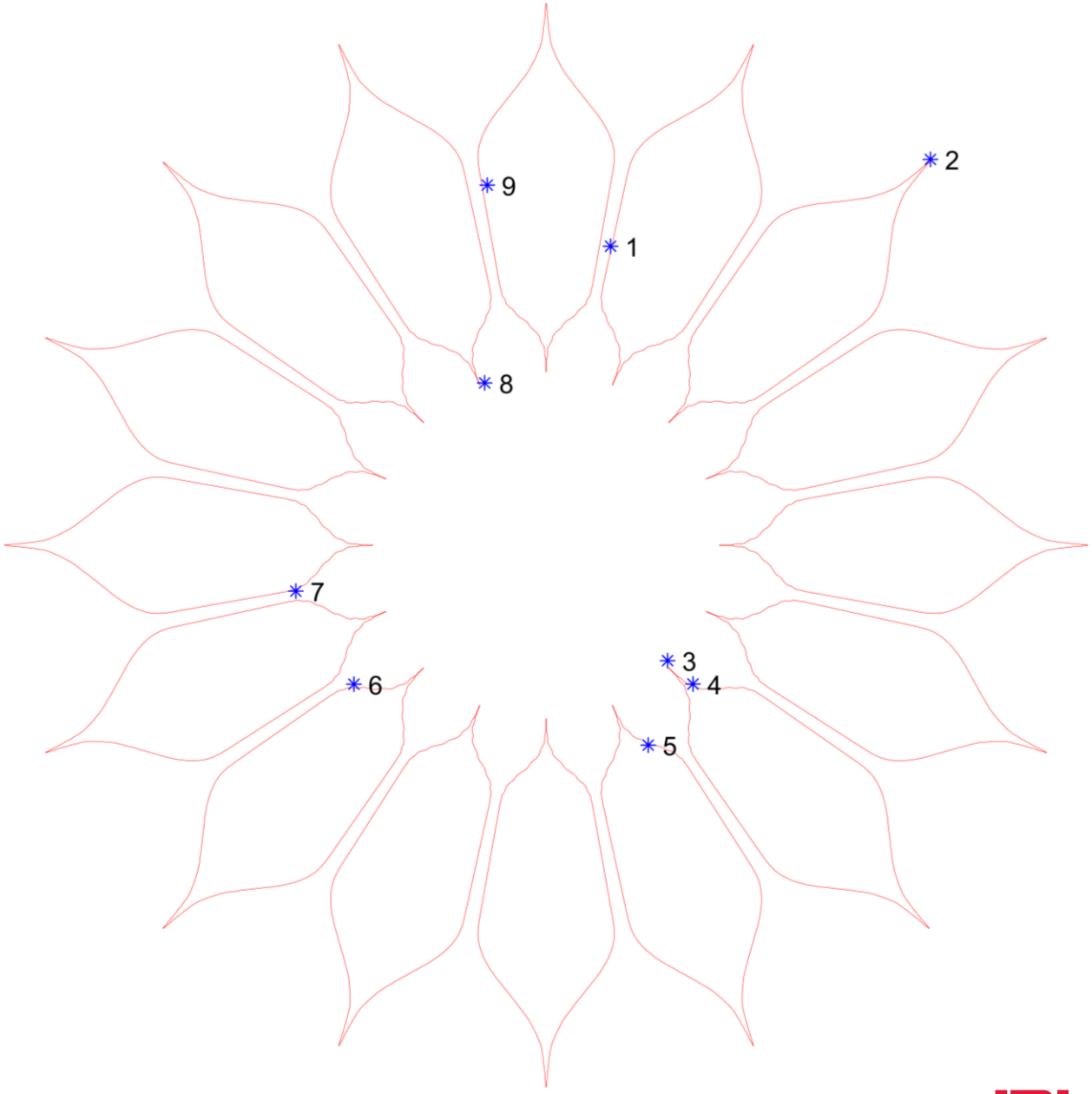
- Mosaic stitched from all 10x Transmission and Reflection Objective images (along the contour of the mask)
- File name: **…/Mosaics/DW21_Full**
- Mosaics of each petals are also found in the same folder



Defects Statistics / Diagram

Direct Write #21 (DW21)

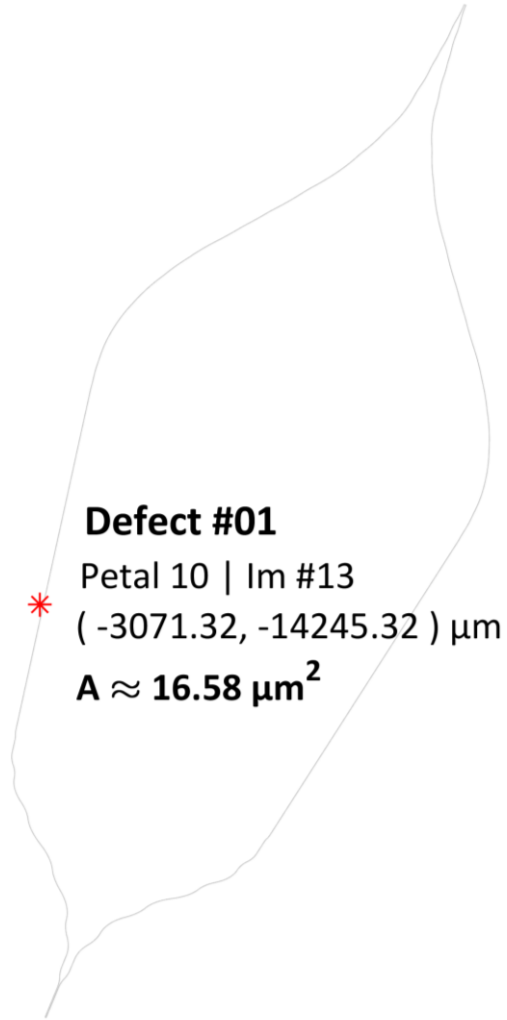
Defect No.	Petal No.	Image No.	Defect area (μm^2)
1	10	13	16.58
2	11	35	19.97
3	15	1	~ 0
4	15	3	5.67
5	16	5	8.54
6	3	61	1.51
7	5	9	80.49
8	8	1	5.75
9	9	18	41.14



e.g. The 10x Image containing Defect #1 is found at
…/Individual Microscope Images/Petal 10/20181227_DW21_P10_10xTxRx_0013.tif

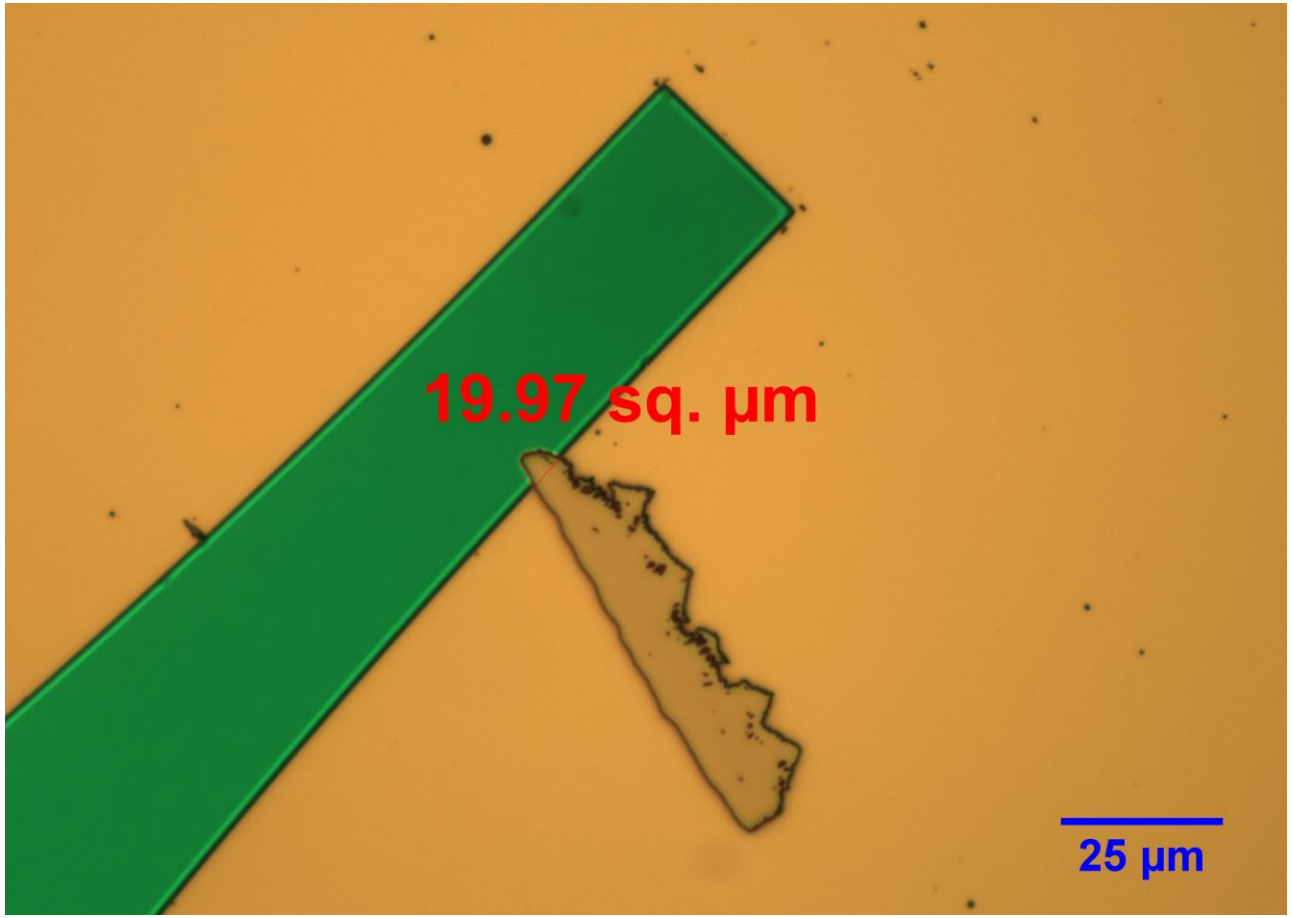
Defect #1

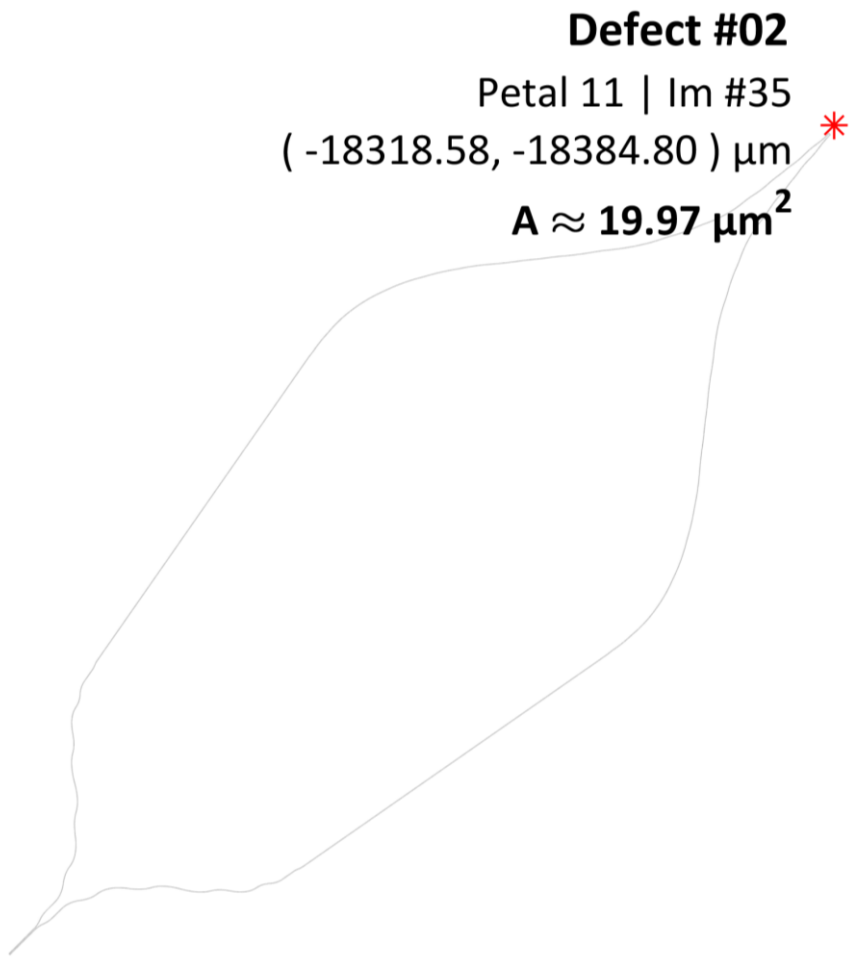
Direct Write #21 (DW21)



Defect #2

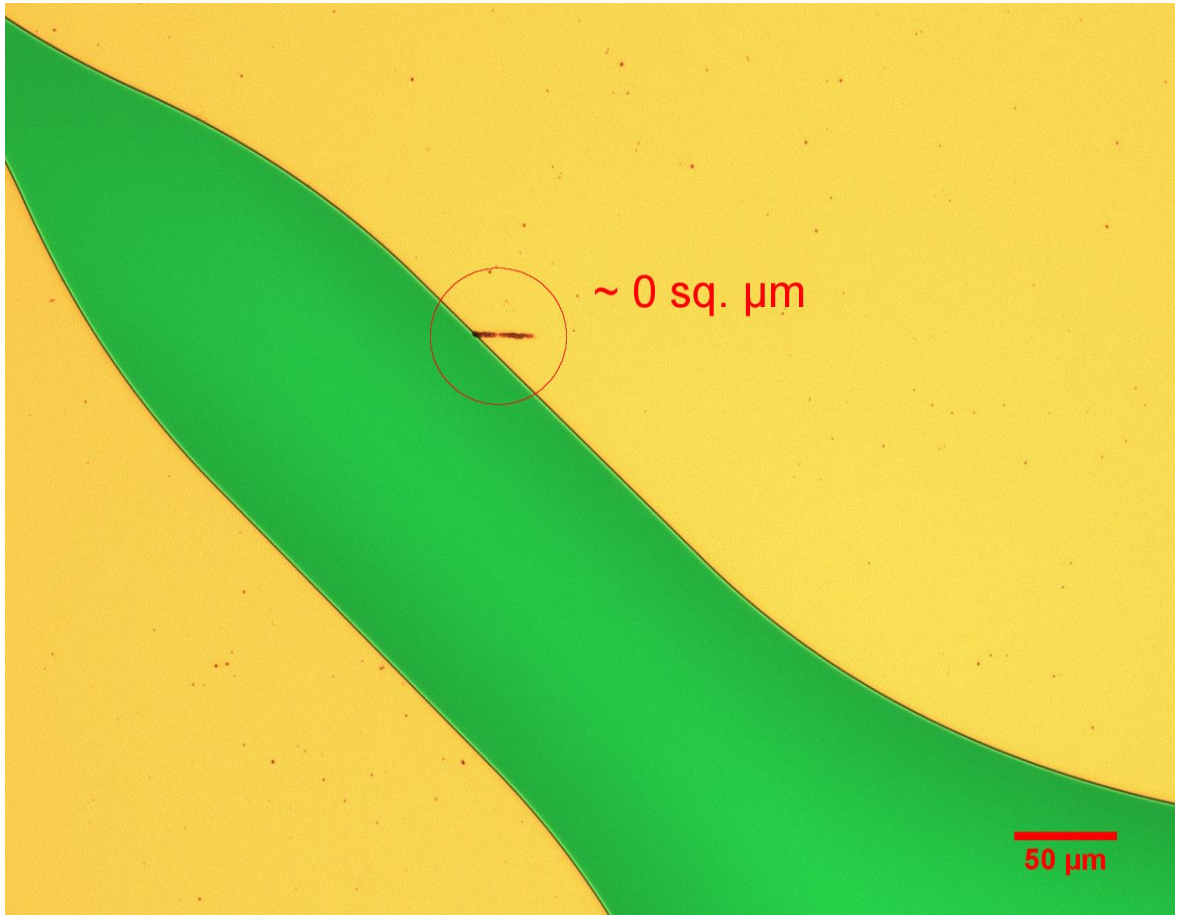
Direct Write #21 (DW21)

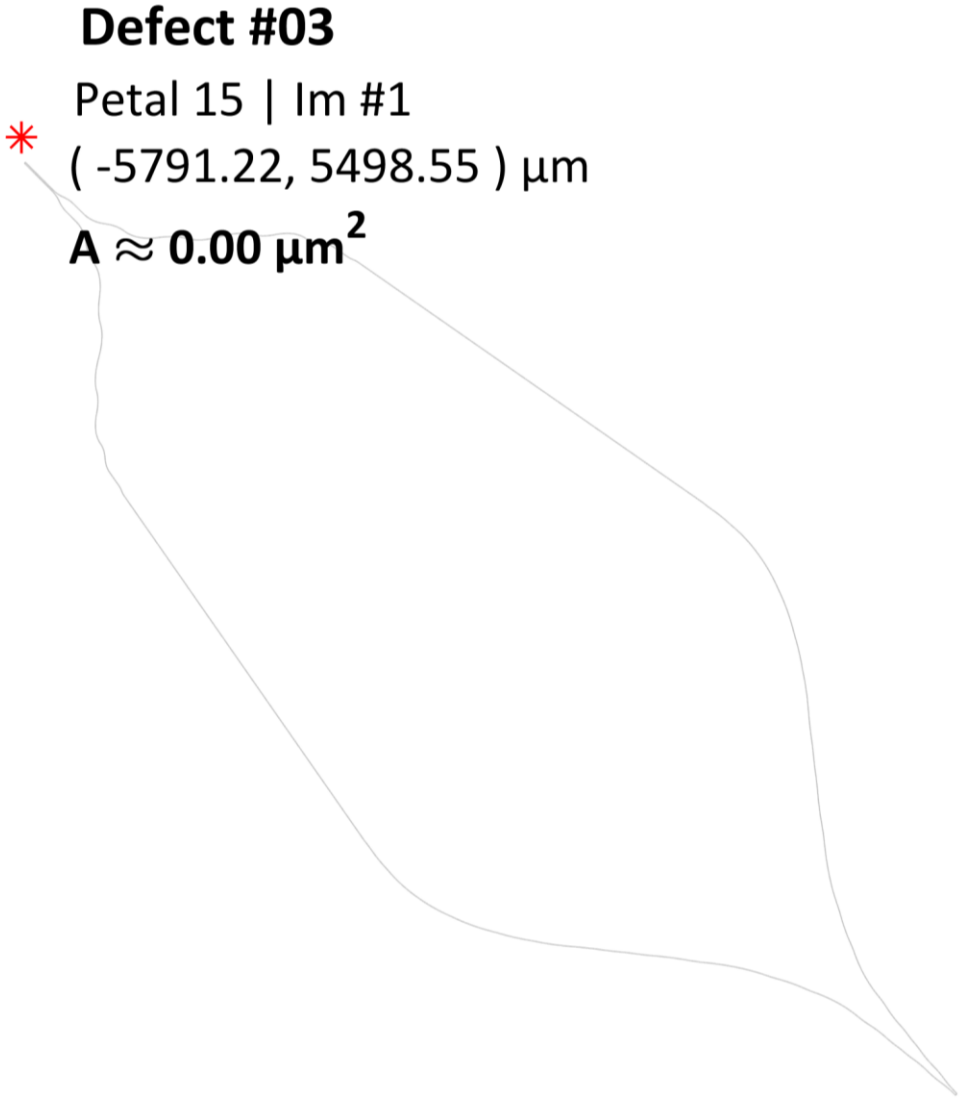




Defect #3

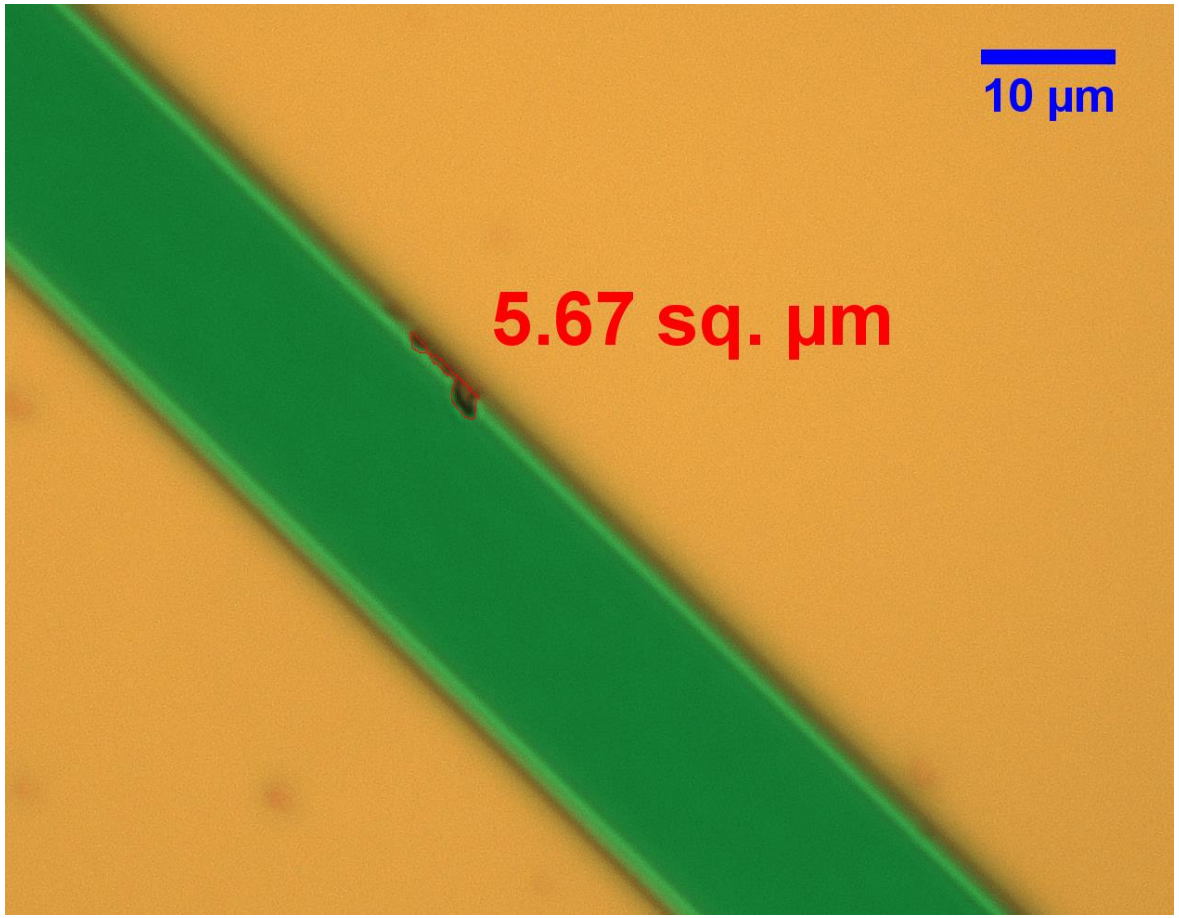
Direct Write #21 (DW21)





Defect #4

Direct Write #21 (DW21)



Defect #04

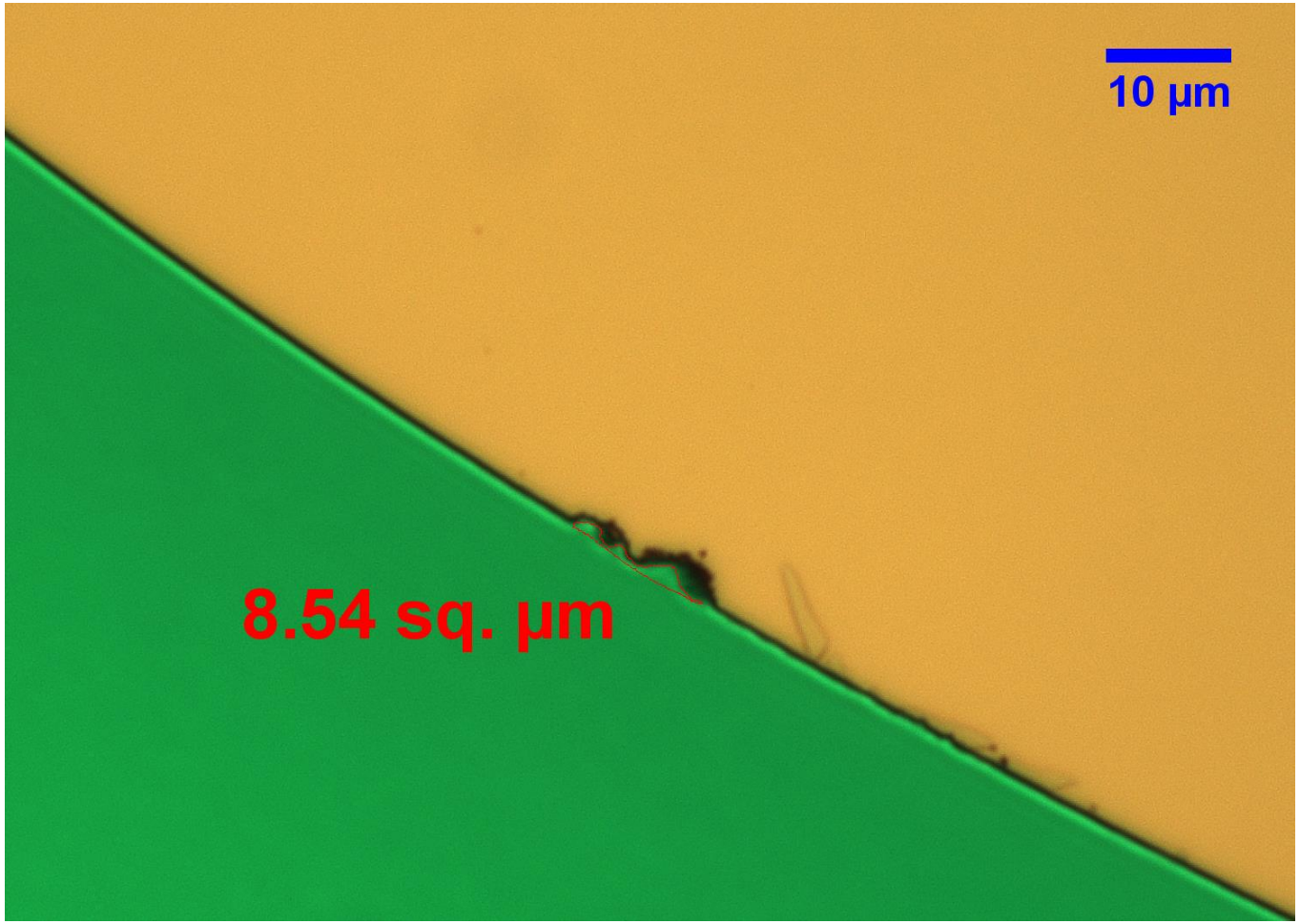
Petal 15 | Im #3

(-6995.94, 6613.63) µm

A ≈ 5.67 µm^2

Defect #5

Direct Write #21 (DW21)



Defect #05

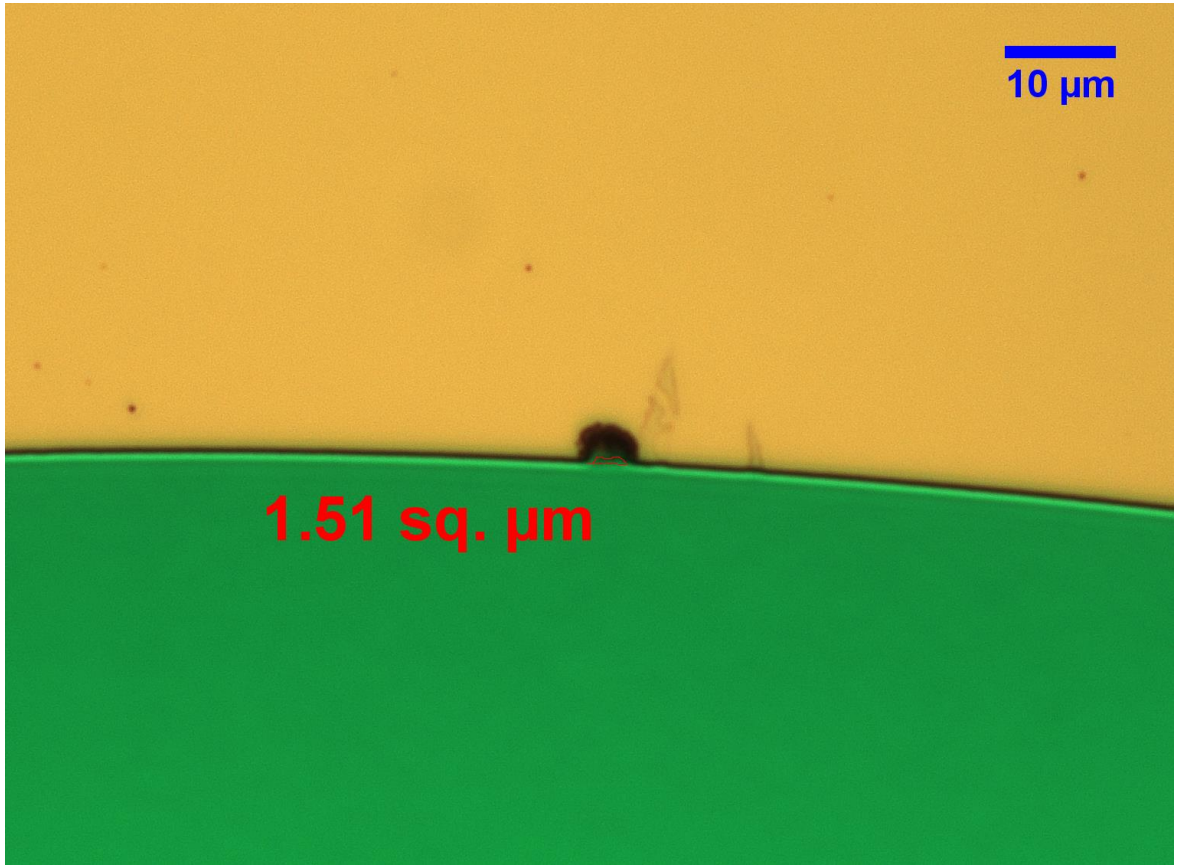
Petal 16 | Im #5

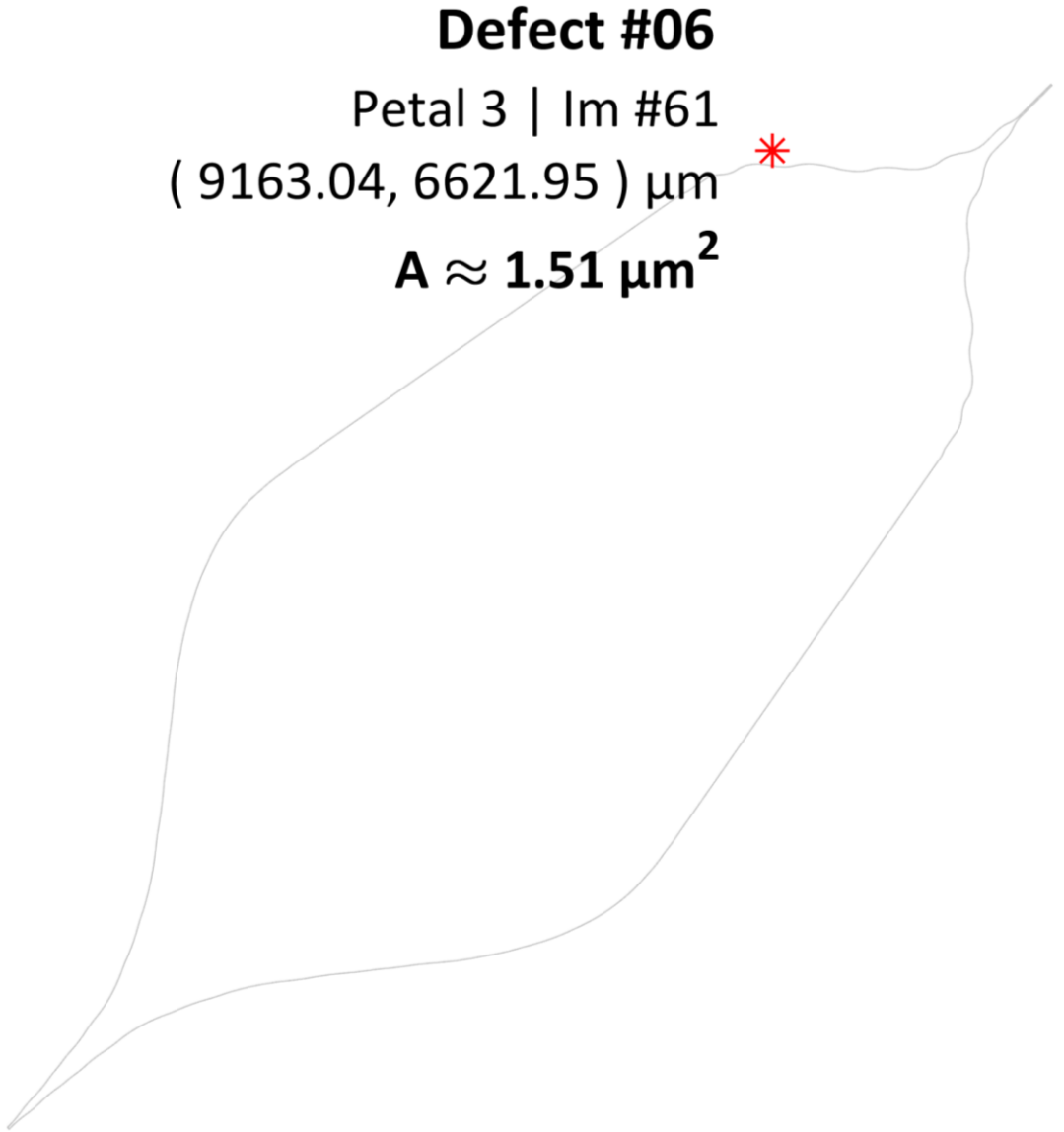
(-4866.18, 9521.52) µm

A ≈ 8.54 µm^2

Defect #6

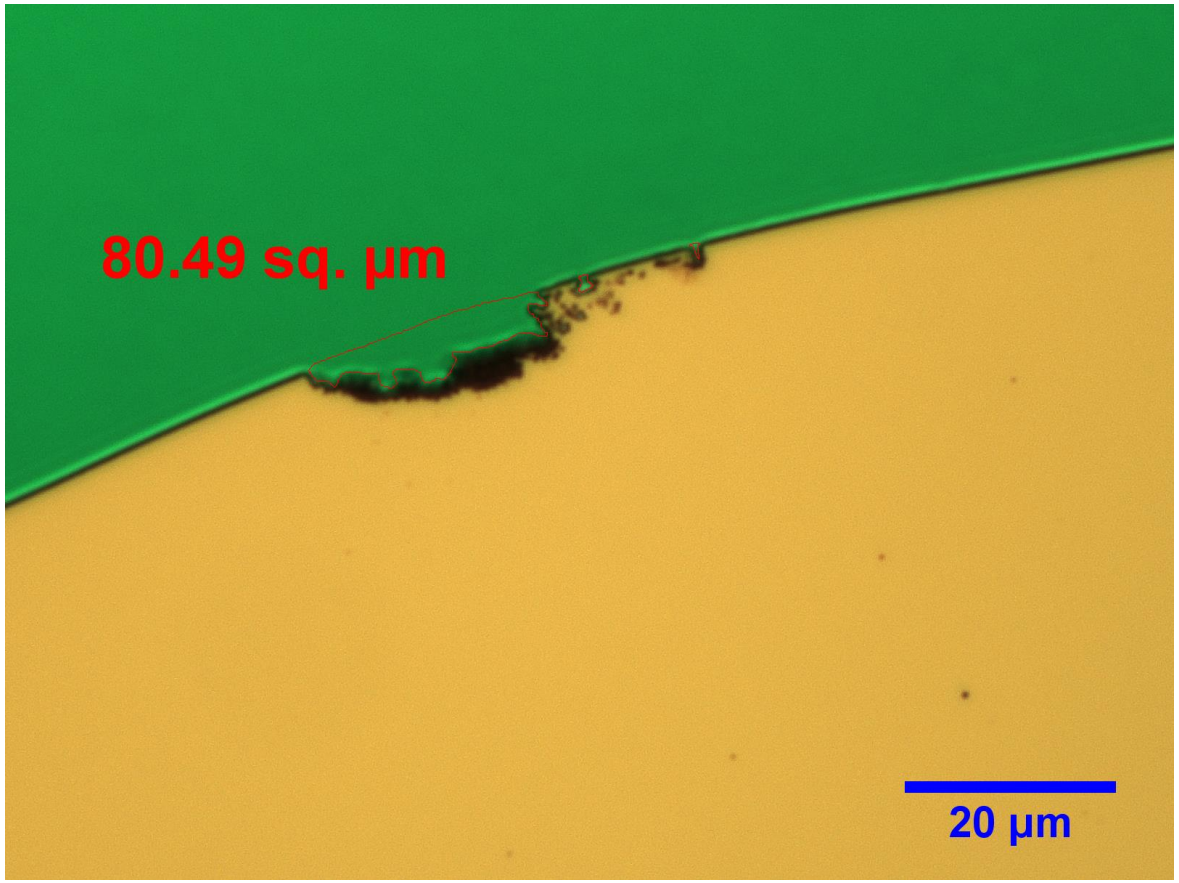
Direct Write #21 (DW21)

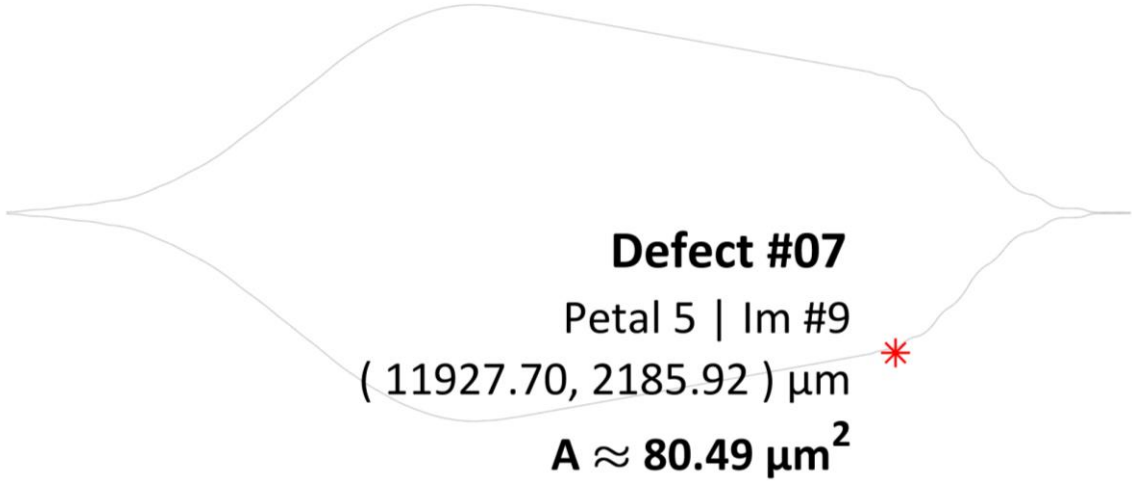




Defect #7

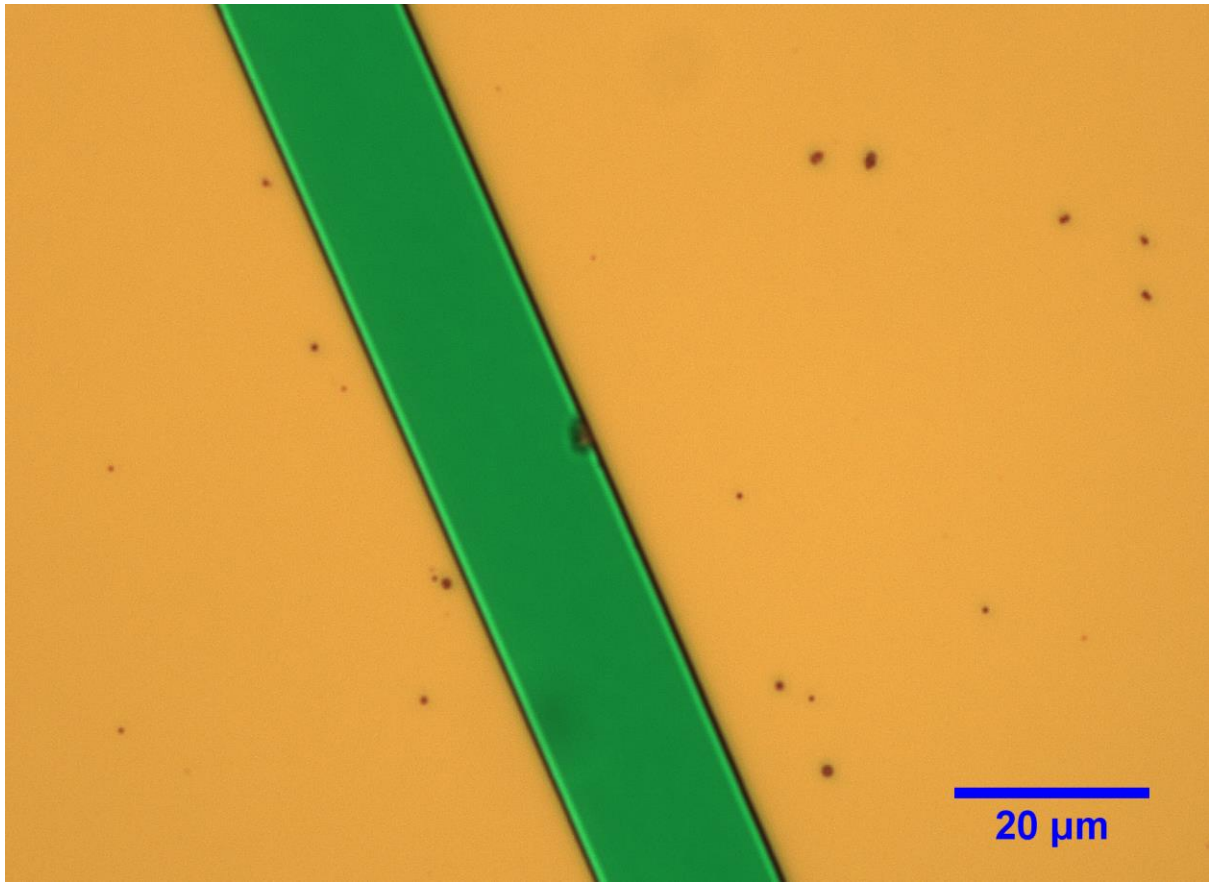
Direct Write #21 (DW21)





Defect #8

Direct Write #21 (DW21)



Defect #08

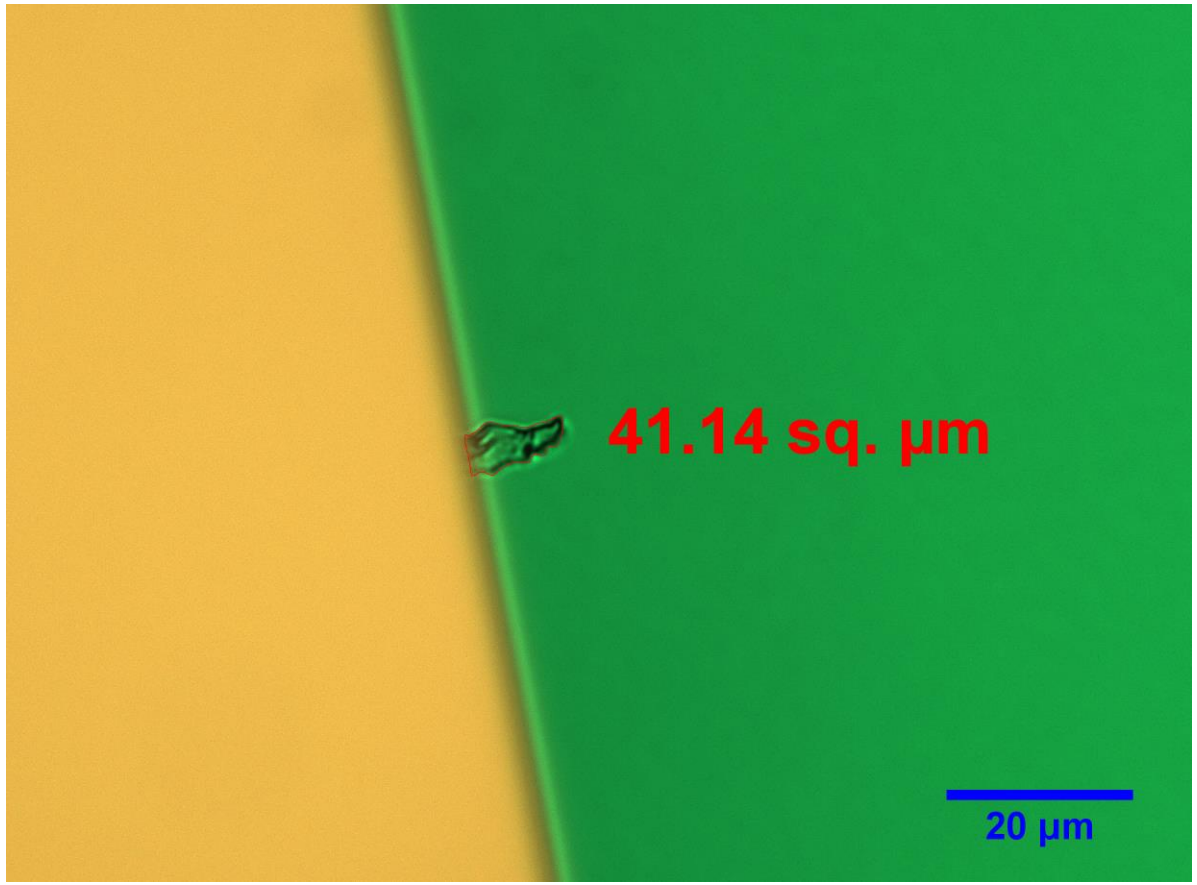
Petal 8 | Im #1

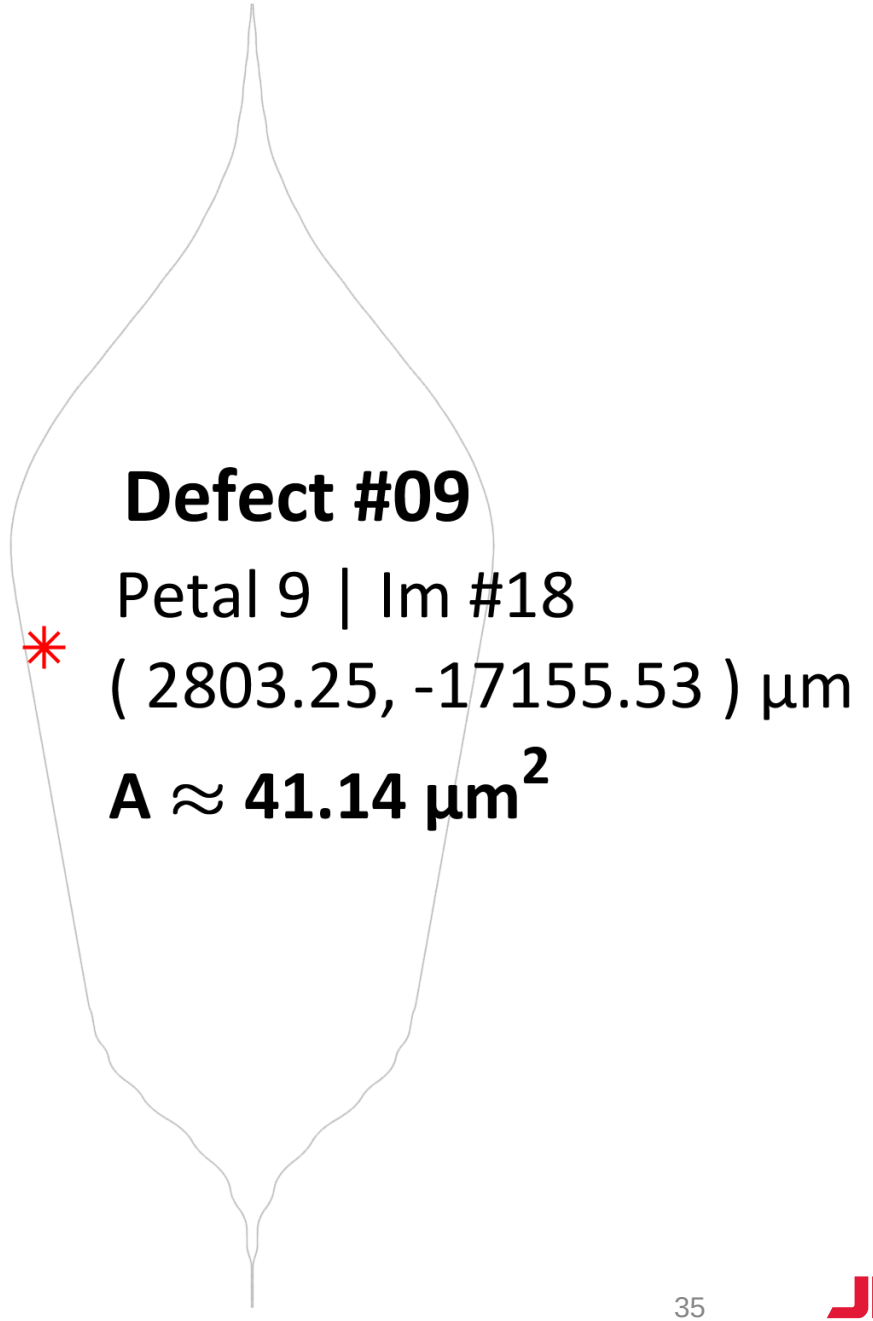
(2929.22, -7732.09) µm

A ≈ 5.75 µm^2

Defect #9

Direct Write #21 (DW21)





Defects Statistics

Direct Write #21 (DW21)

Defect No.	Petal No.	Image No.	X (μm)	Y (μm)	Distance to Spine (μm)	Distance from Inner Tip (μm)	Area ($μm^2$)
1	10	13	3071.32	14245.32	3071.32	40057.64	16.58
2	11	35	18318.58	18384.80	18318.58	44197.11	19.97
3	15	1	5791.22	-5498.55	5791.22	20313.76	~ 0
4	15	3	6995.94	-6613.63	6995.94	19198.69	5.67
5	16	5	4866.18	-9521.52	4866.18	16290.79	8.54
6	3	61	-9163.04	-6621.95	9163.04	19190.36	1.51
7	5	9	-11927.70	-2185.92	11927.70	23626.40	80.49
8	8	1	-2929.22	7732.09	2929.22	33544.41	5.75
9	9	18	-2803.25	17155.53	2803.26	42967.85	41.14

With (0, 0) being the center of the starshade mask
[not the Wafer]

Acknowledgements

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

The authors thank the Princeton University High Contrast Imaging Lab team under Prof. J. Kasdin for their support with the design of Star Shade Masks over several years.

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov