# Computational modeling of CMP pads: a die-scale model incorporating measured surface roughness

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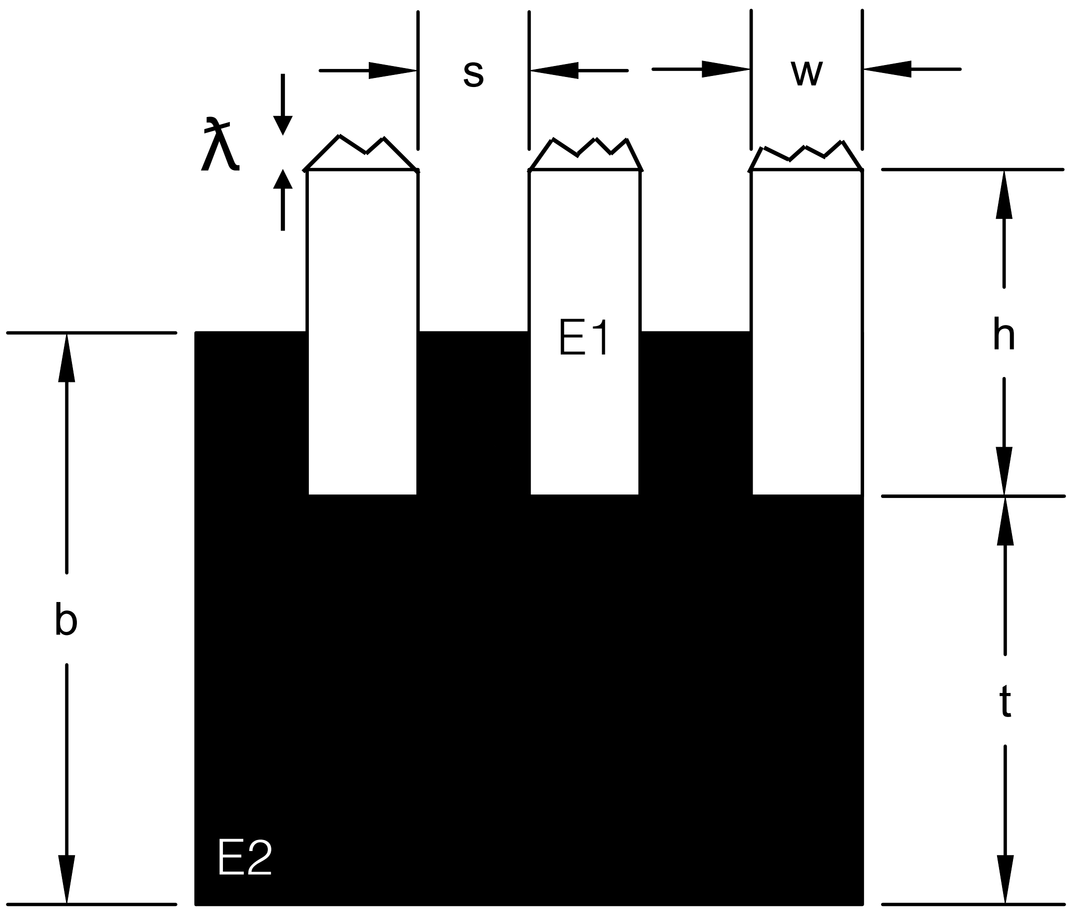
# Outline

1. Introduction
    - Background, motivation, and research objective
2. Computational modeling
    - Die-scale modeling
    - Feature-scale modeling
    - Incorporating the role of pad surface asperities
3. Results
4. Conclusion

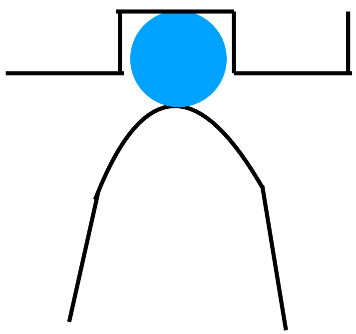
# I parametrize the pad with 6 geometric and 3 mechanical parameters




| Parameter | Range |
|---|---|
| **E1** | 500 - 5000MPa |
| **E2** | 1 - 100MPa |
| **w** | 0.25 - 3 mm |
| **s** | 0.25 - 3 mm |
| **h** | 0.25 - 1 mm |
| **t** | 0.25 - 2 mm |
| **b** | 0.5 - 2.5 mm |
| **ƛ** | 10 - 100 μm |

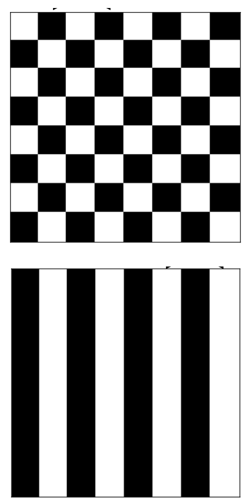
# CMP modeling is required at multiple scales

### Particle Scale



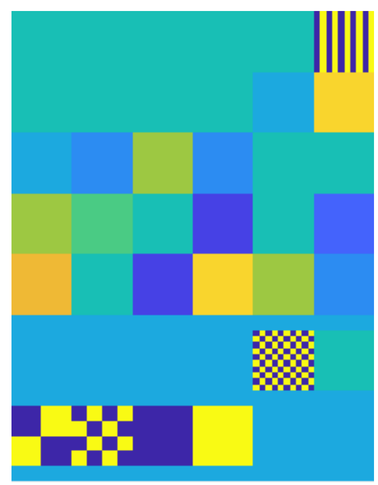
Particle size and concentration

### Feature Scale



Feature shape, width, and height

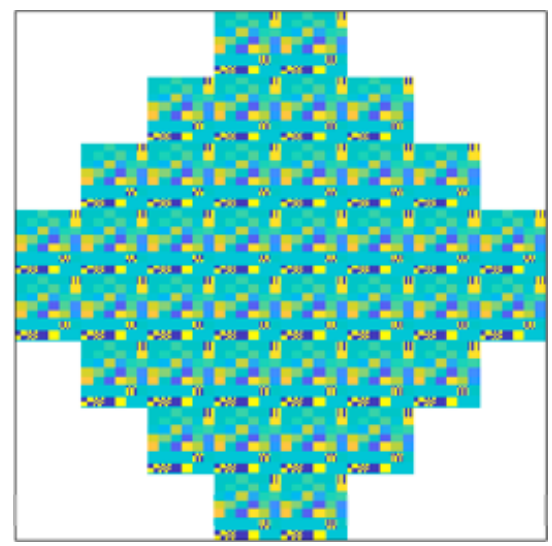
### Die Scale



Pattern density

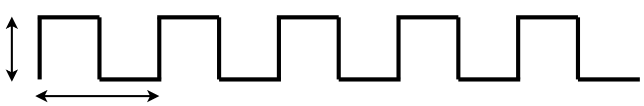
Neighboring effects

### Wafer Scale

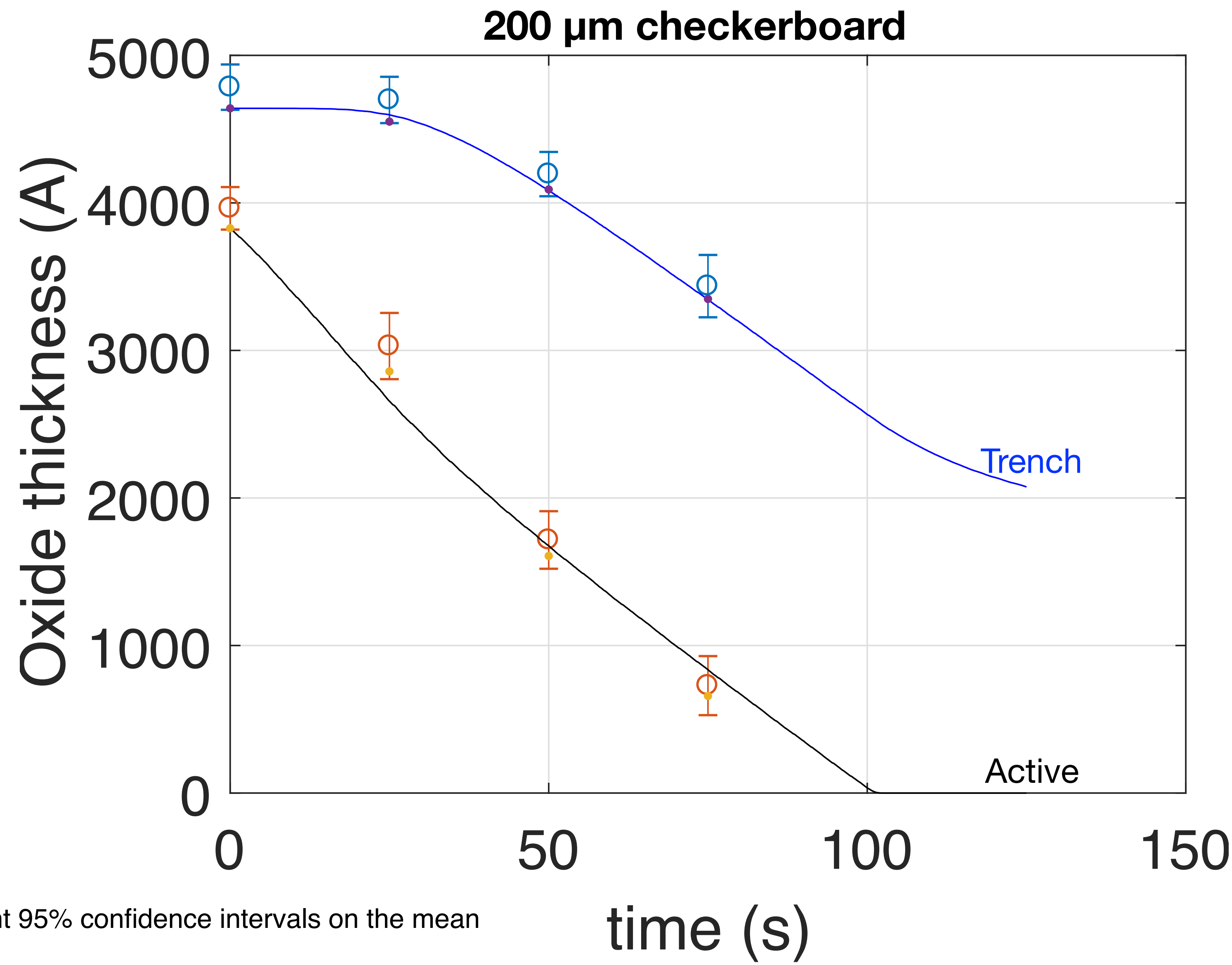


Average pattern density

Edge effects



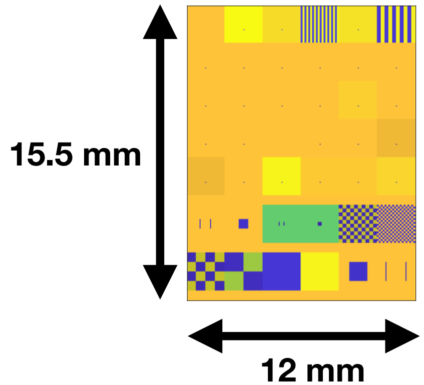
# Goal: predict oxide thickness vs time for a given pad design




*error bars represent 95% confidence intervals on the mean
Lines: Simulations
Error bars: Experiments

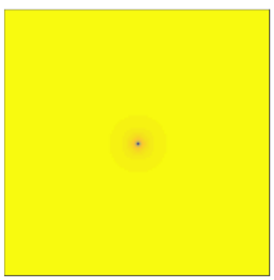
# Hypothesis: CMP can be modeled using a contact wear approach that accounts for both bulk and surface pad deformation

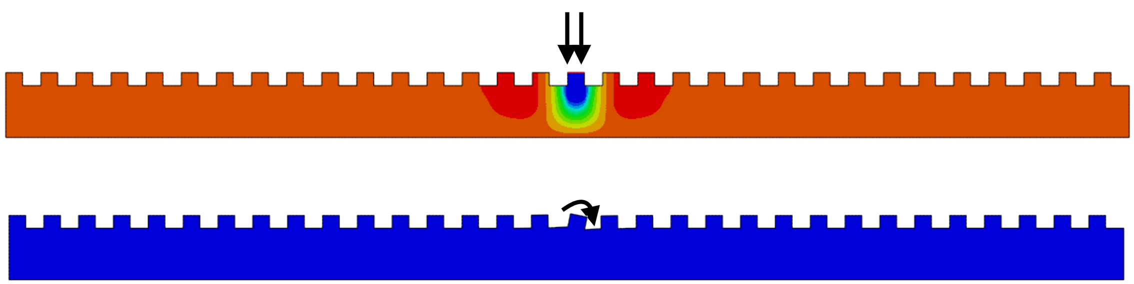
Start with initial topography



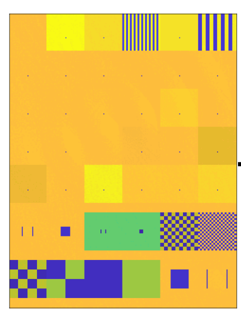

Rotate/sweep system

Place into contact with segmented pad





Remove material



**Has the total polish time elapsed?**

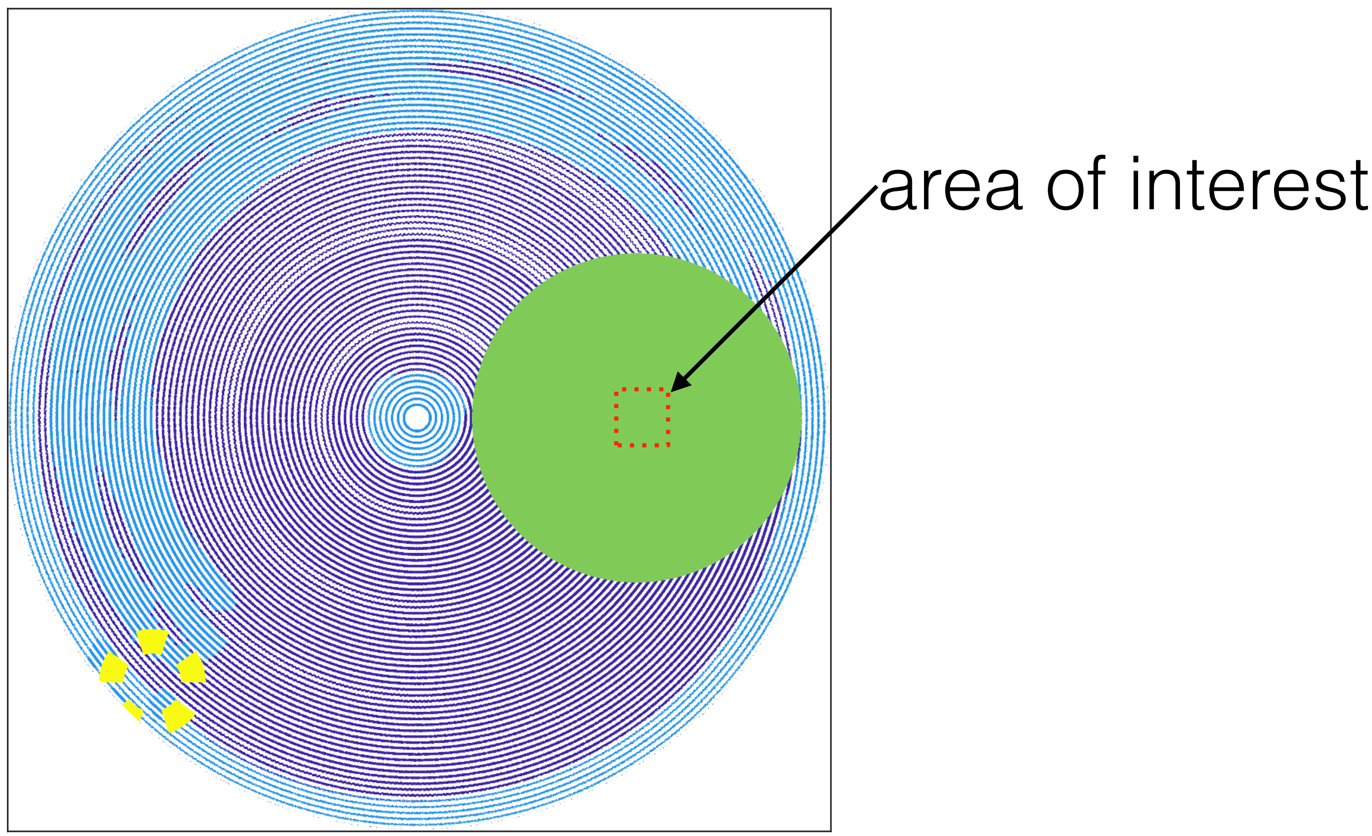
**No**

**Yes**

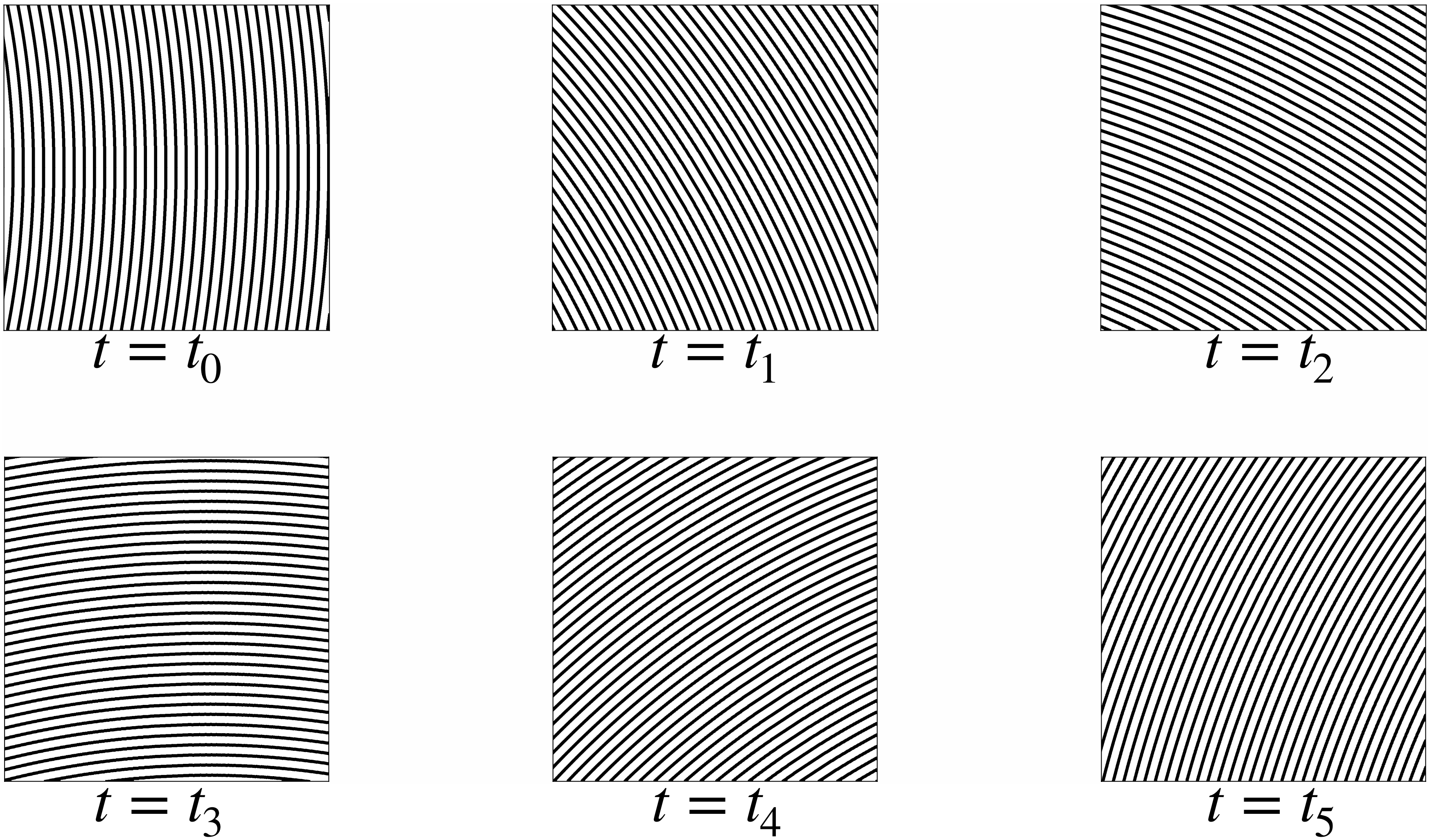
Calculate outputs

## Computational modeling

# We'll focus on the die that is at the very center of the wafer

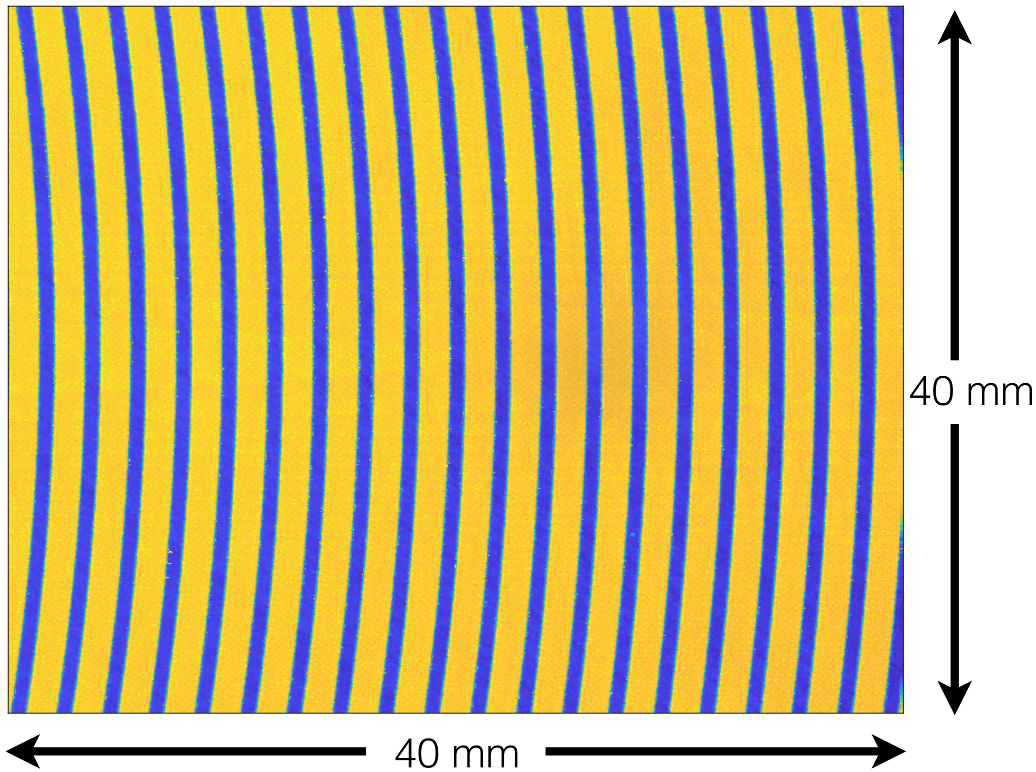


# Pad segments rotate and horizontally translate across the die

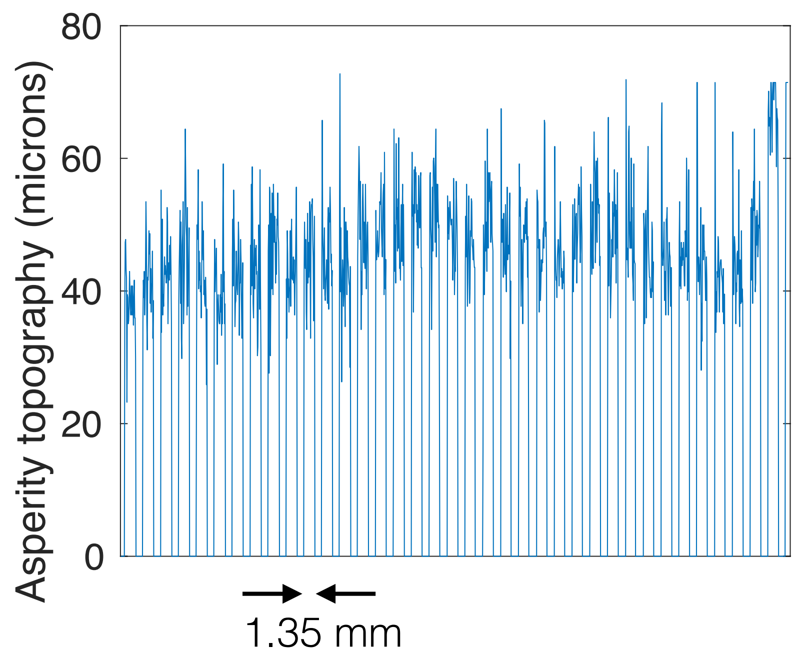



Pad platen: 93 rpm
Wafer platen: 87 rpm
Wafer center sweeps from 7.5” to 8.5” away from pad center

# We use a Solarius confocal microscope to 3D scan large areas of the pad surface




Top view

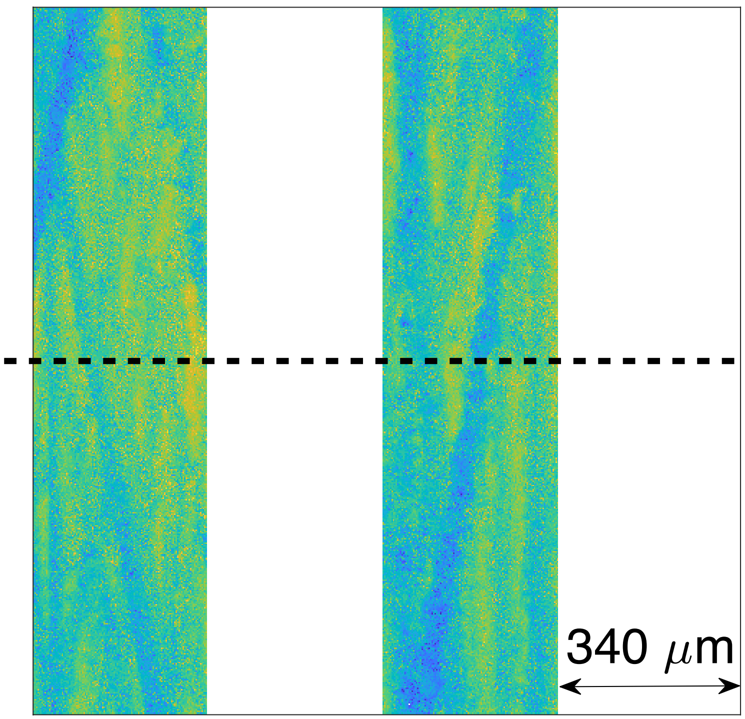



Cross section

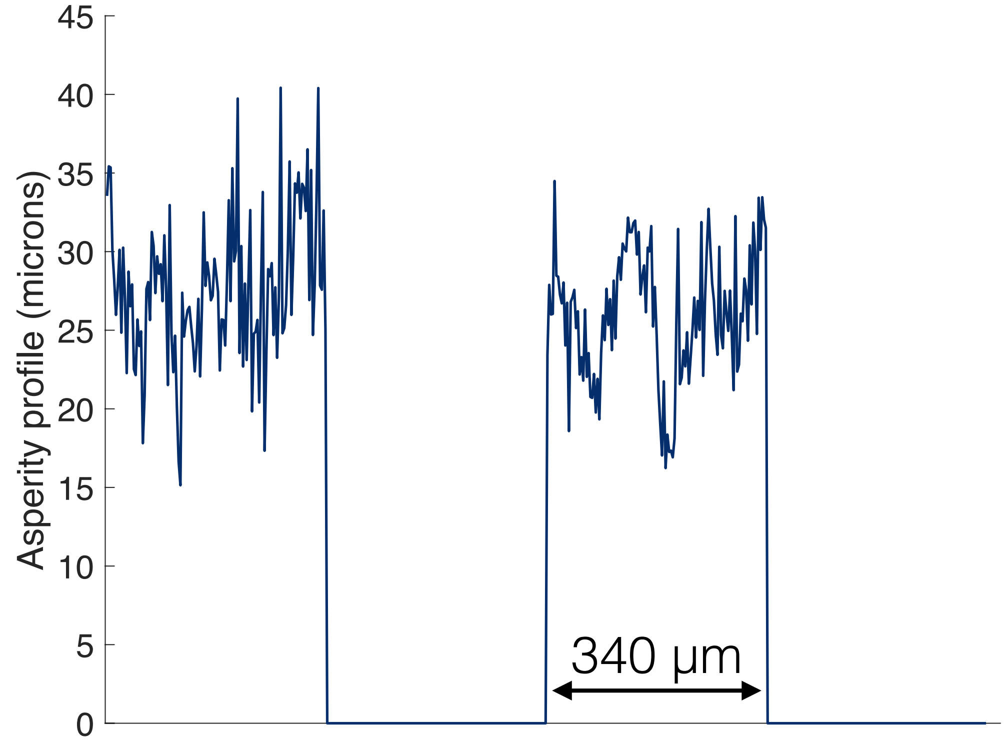
- Solarius allows for scanning large areas with a 25 μm resolution

[1] Brian Salazar, et al., "Die-scale modeling of planarization efficiency using segmented CMP pads: analyzing the effects of asperity topography" presented at the International Conference on Planariza- tion/CMP Technology (ICPT), Hsinchu, Taiwan, September 2019.

# We use a 3D laser scanning confocal microscope to scan small portions of the pad surface at high resolution (~2.5 $\mu$m)



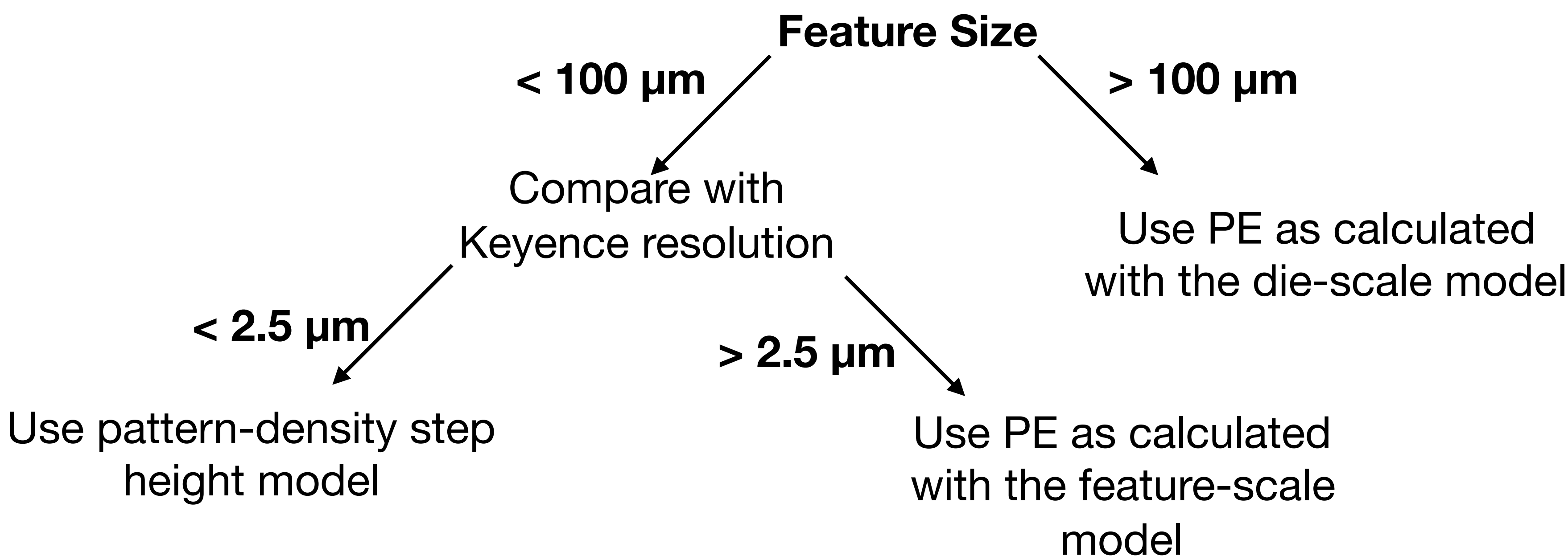

Pad Top View




Pad Cross Section

[2] Brian Salazar and Hayden Taylor, "Computational modeling of segmented CMP pads; incorporating the effects of asperity topography" presented at the 22nd International Symposium on Chemical-Mechanical Planarization (CMP), Lake Placid, NY, August 2018.

# Sub-pixel behavior (die-scale model is run at 50 µm pixel size)



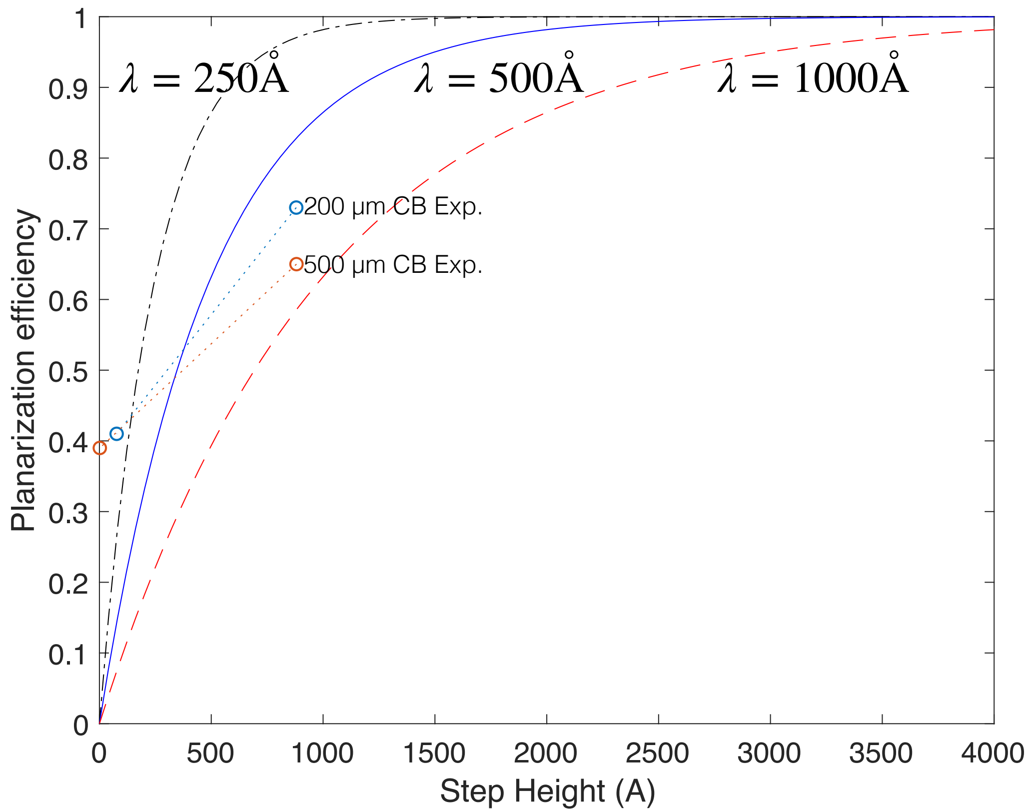
Features < 2.5 μm

# The PDSH model is effectively dictating a PE vs SH profile (for the small features)

$$P_{\textbf{active}} = \frac{P(x,y)}{1+(\rho-1)PE}$$

$$P_{\textbf{trench}} = \frac{(1-PE)P(x,y)}{1+(\rho-1)PE}$$

$$PE = 1-\exp\left(-\frac{h}{\lambda}\right)$$

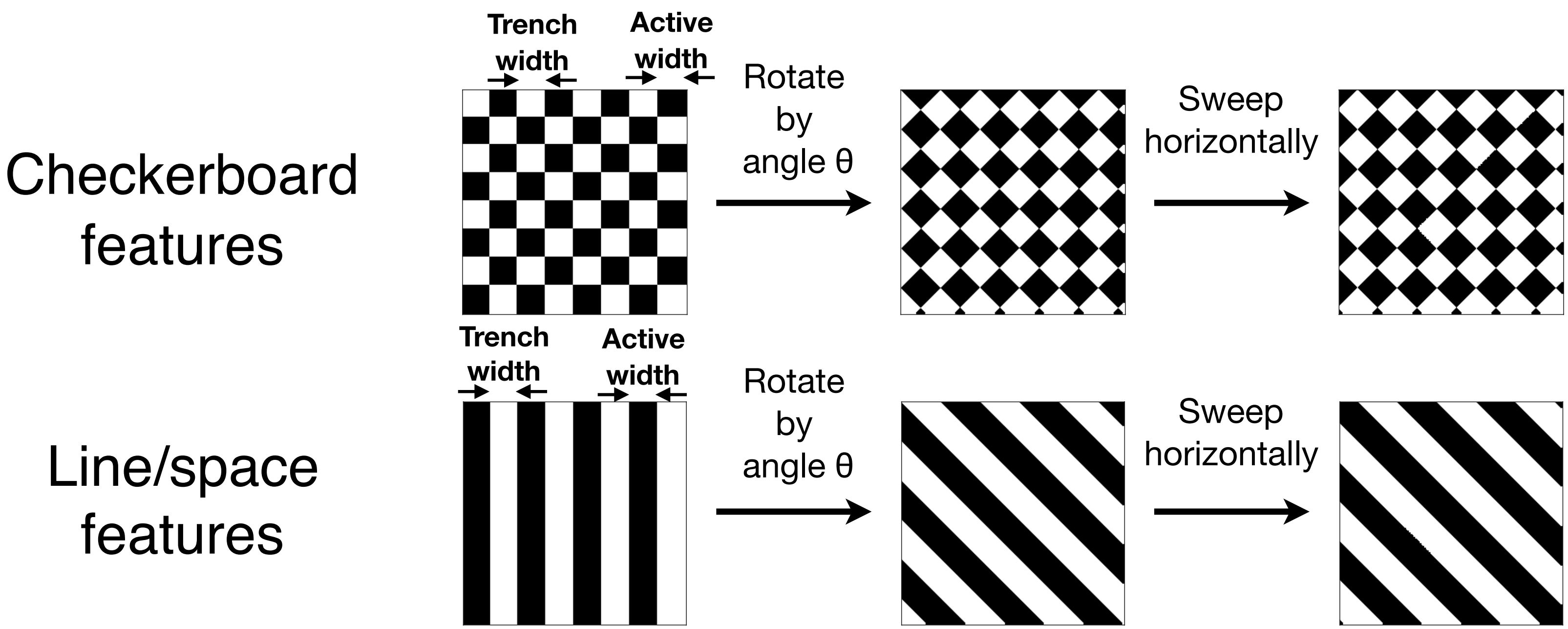



For small features, λ is likely to be the dominant parameter (over bulk parameters)

[4] Xie, X. (2007). Physical Understanding and Modeling of Chemical Mechanical Planarization in Dielectric Materials. Massachusetts Institute of Technology.

# Features > 2.5 μm and < 50 μm

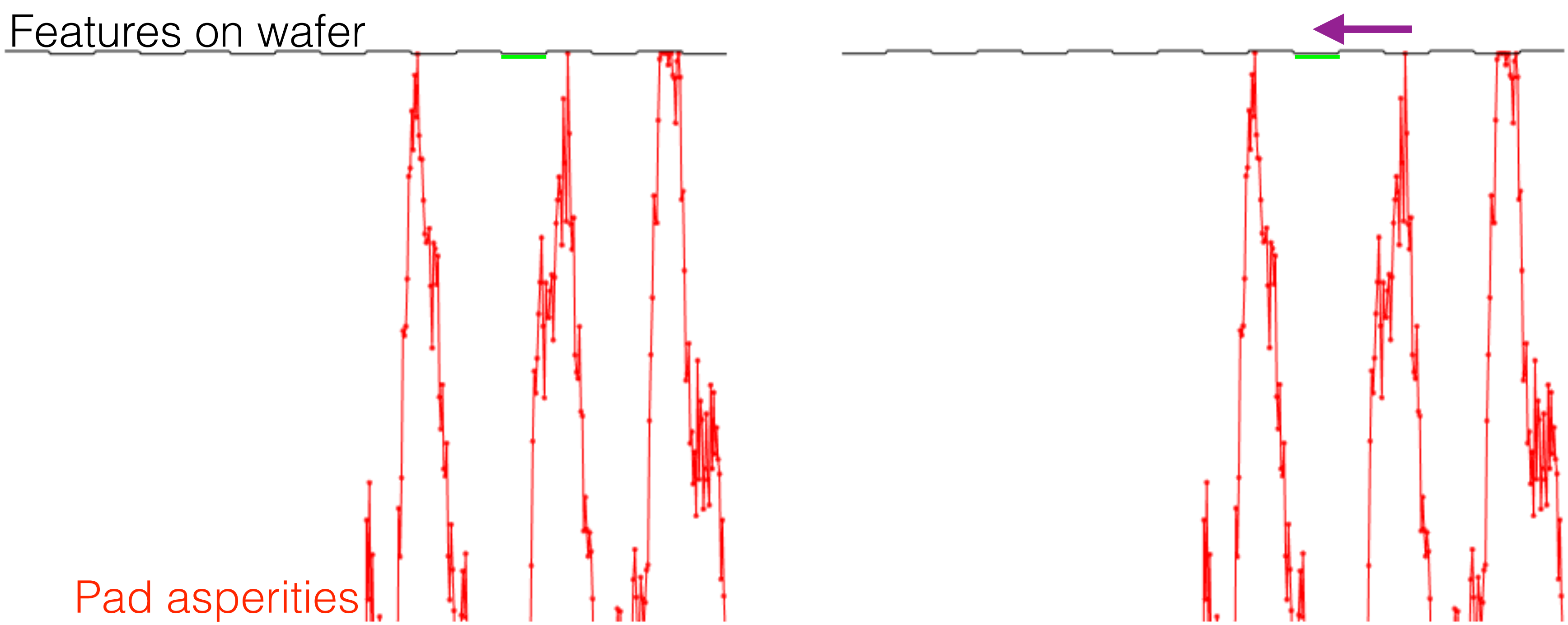
## Compute the solid-solid contact pressure distribution between pad segments and wafer features at all possible configurations




[5] Brian Salazar and Hayden Taylor, "Computational modeling of segmented CMP pads; incorporating the effects of asperity topography" presented at the 22nd International Symposium on Chemical-Mechanical Planarization (CMP), Lake Placid, NY, August 2018

Features > 2.5 μm and < 50 μm

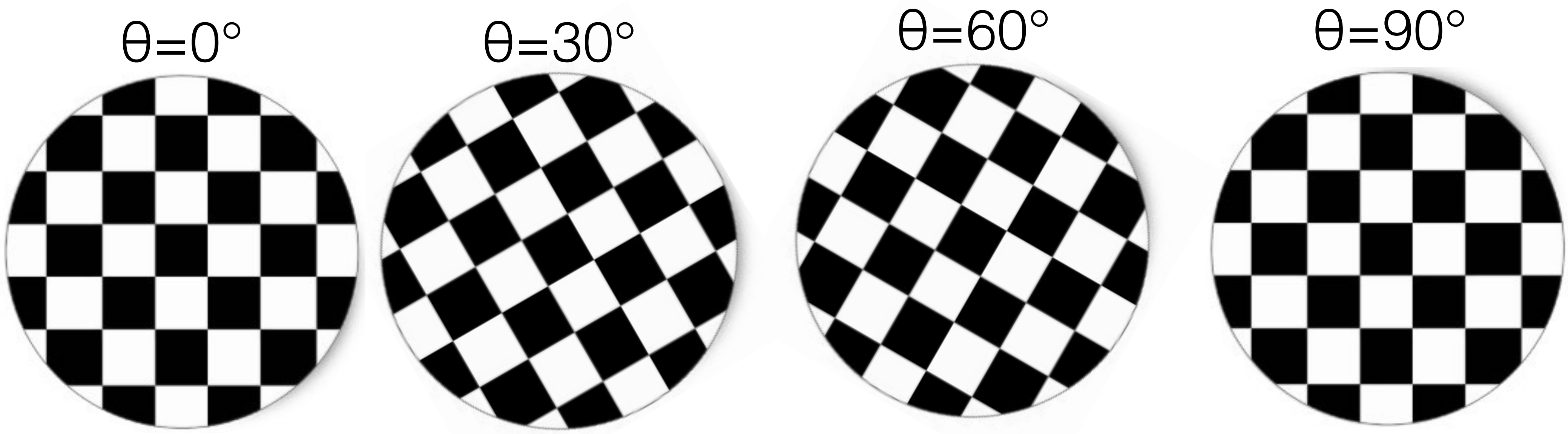
# We sweep the feature topography across the pad, to allow for all contact situations




Sweep the feature relative positions across a segment

- Average pressure distribution over all possible relative positions

# We simulate ten possible relative angle between features and segments

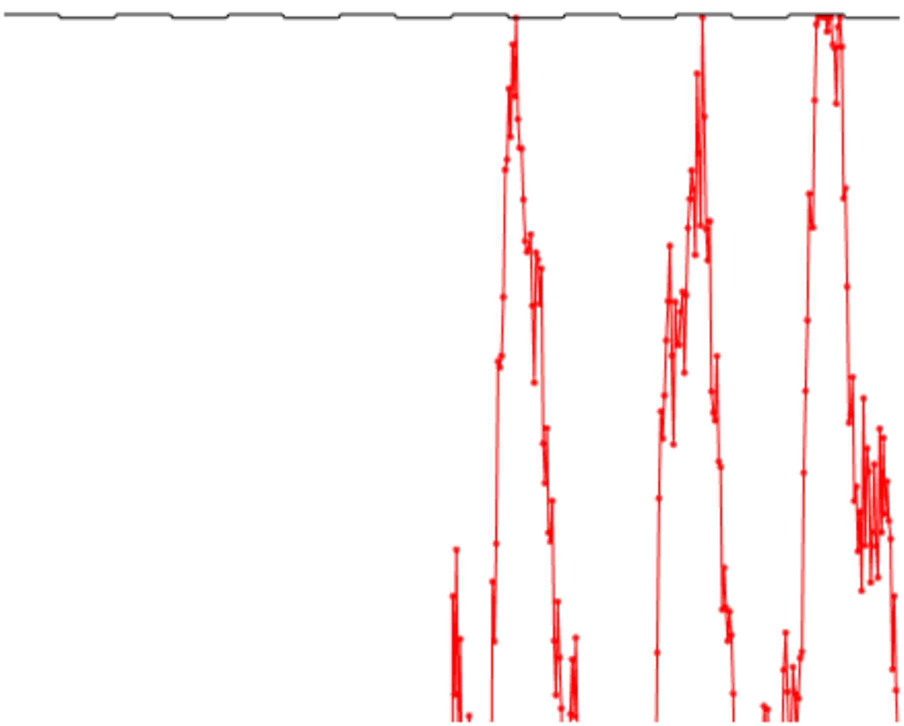



Rotationally symmetric pad

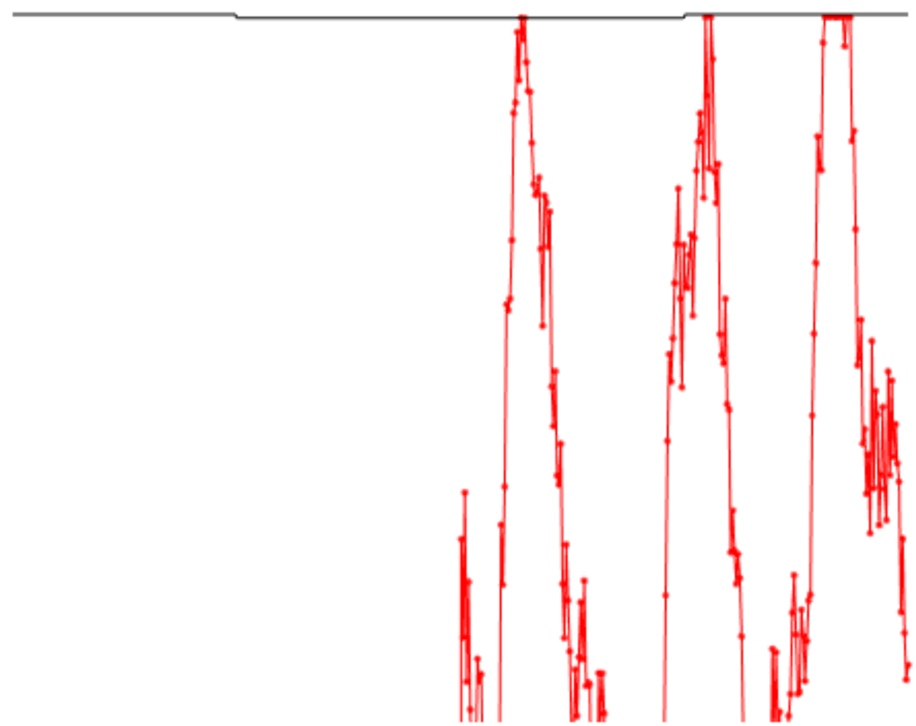
Average the pressure calculations over all ten simulated relative angles

Features > 2.5 μm and < 50 μm

## We are interested in the planarization efficiency for various feature sizes, and step heights



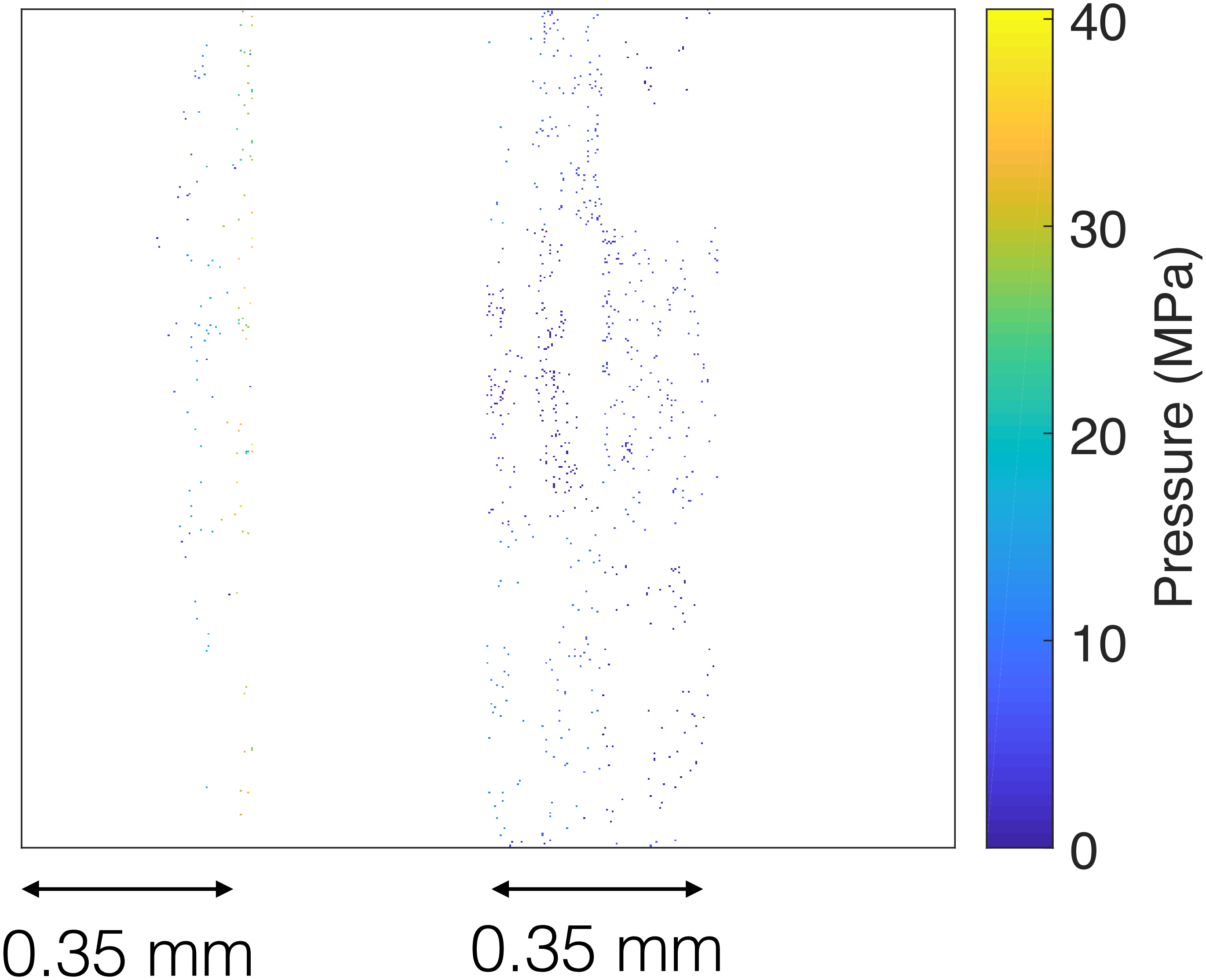
Small Features



Large Features

Run contact simulations for features much smaller to bigger than the segment size

# Simulated contact pressure distribution: contacts are sparse, with <0.4% of locations having non-zero pressure



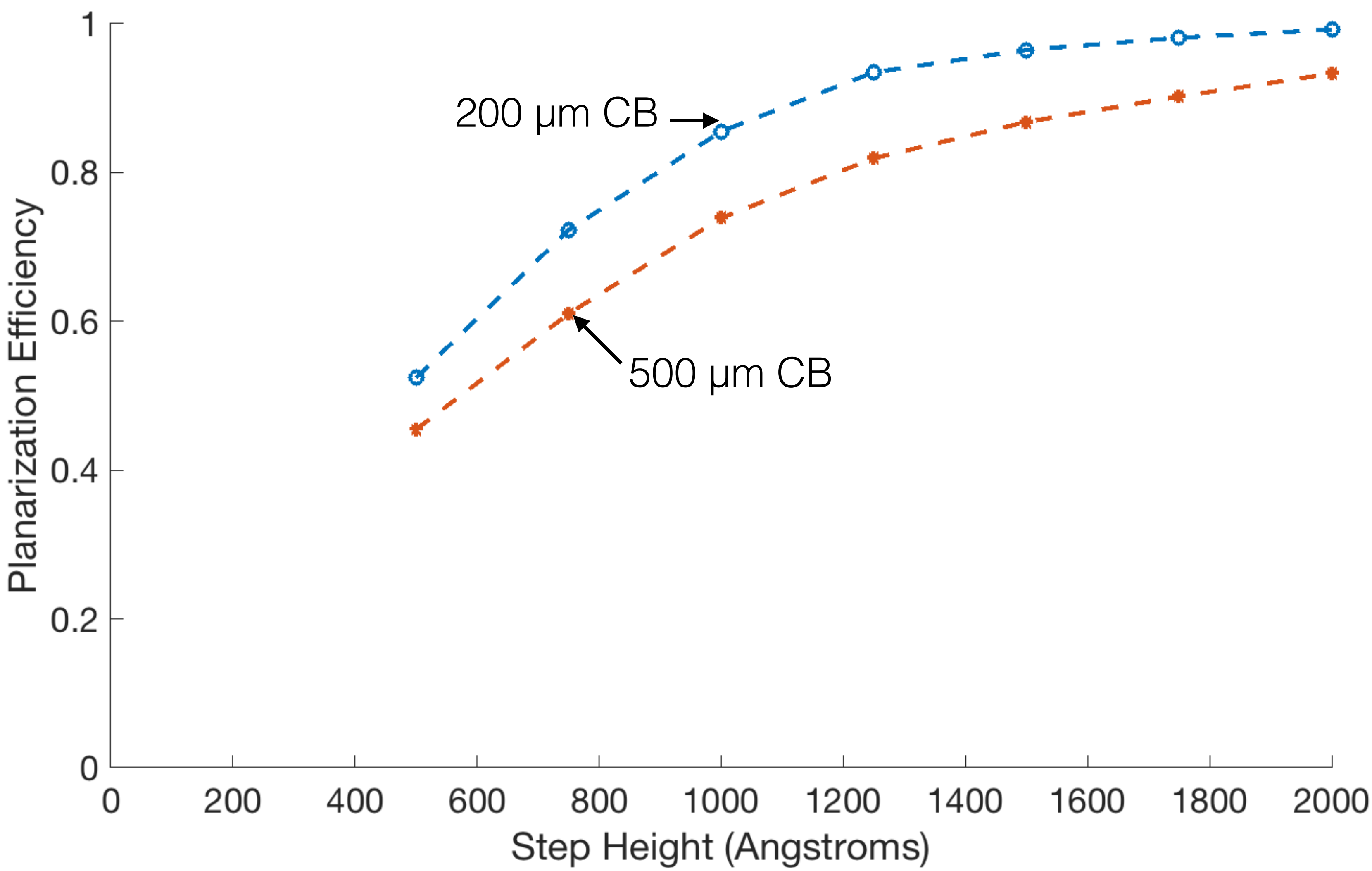
# Probing the pressure distribution at the trench and active allows us to calculate PE, assuming the material is Prestonian

- Assume the slurry + system is Prestonian

$$MRR = Kvp$$

$$PE = 1 - \frac{MRR_{\text{trench}}}{MRR_{\text{active}}} = 1 - \frac{P_{\text{trench}}}{P_{\text{active}}}$$

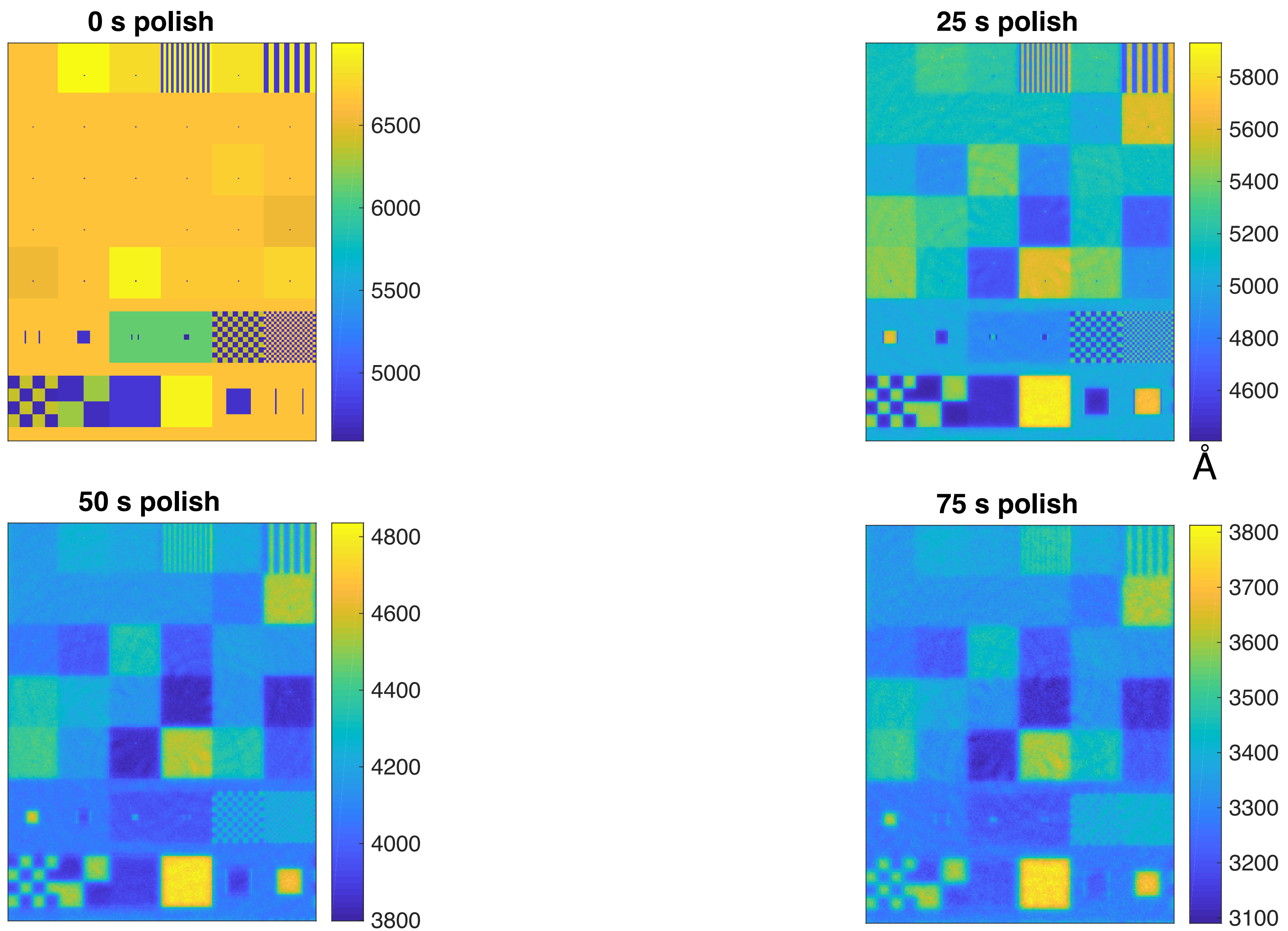
# Simulations show smaller step heights experience lower planarization efficiency



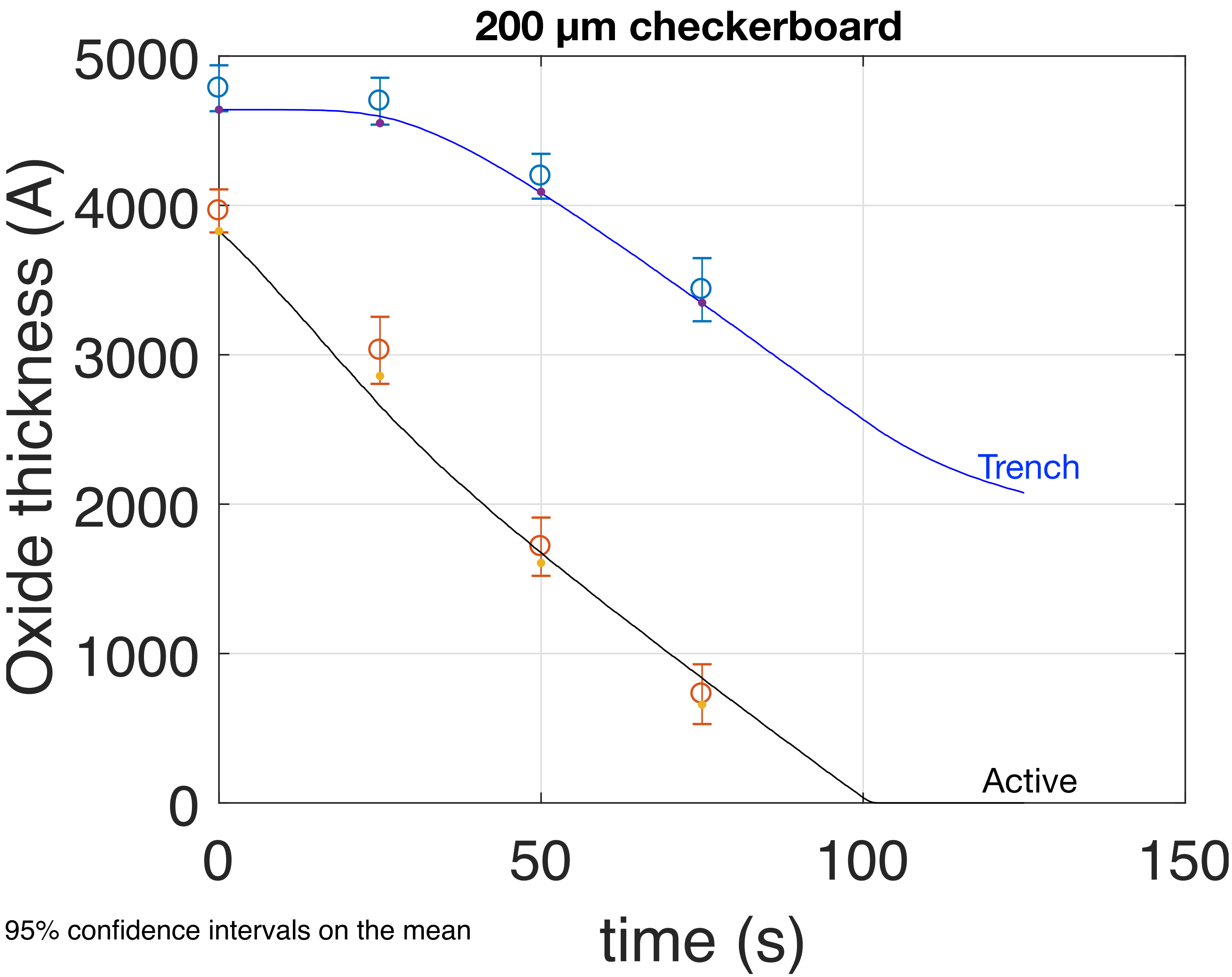

Simulations

**Results - Feature scale**

# Simulated die topographies show the oxide becomes more planar as the polish continues

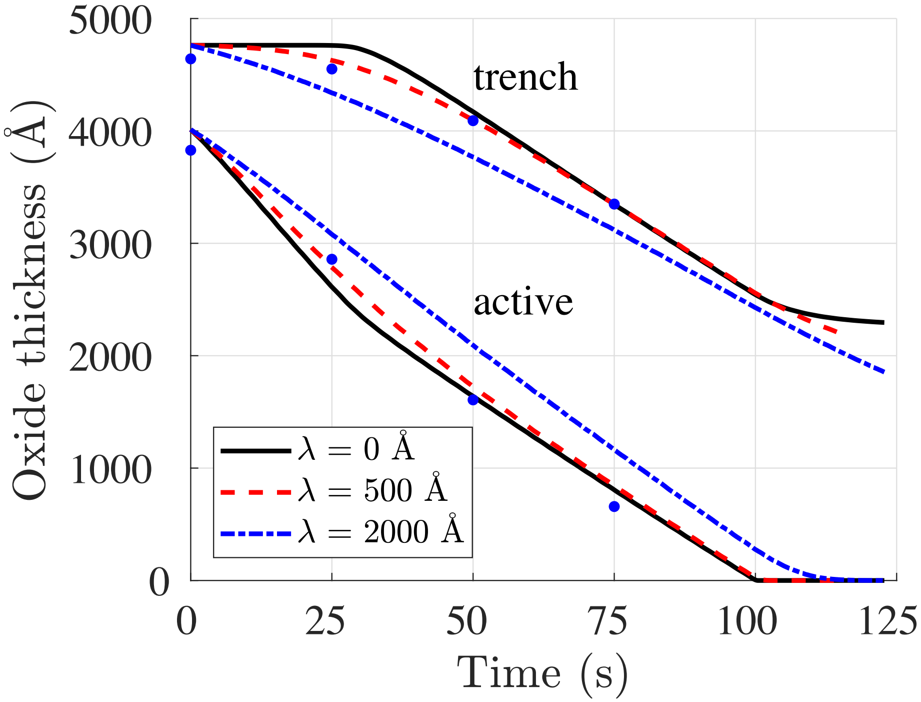


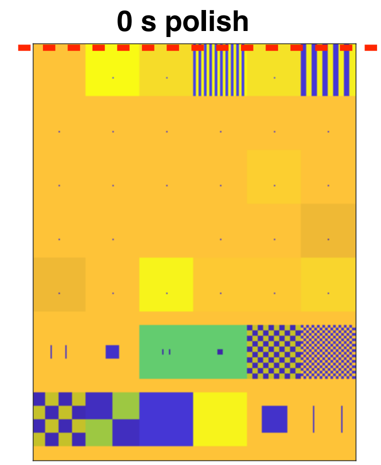
# Simulations show reasonable agreement with experiments



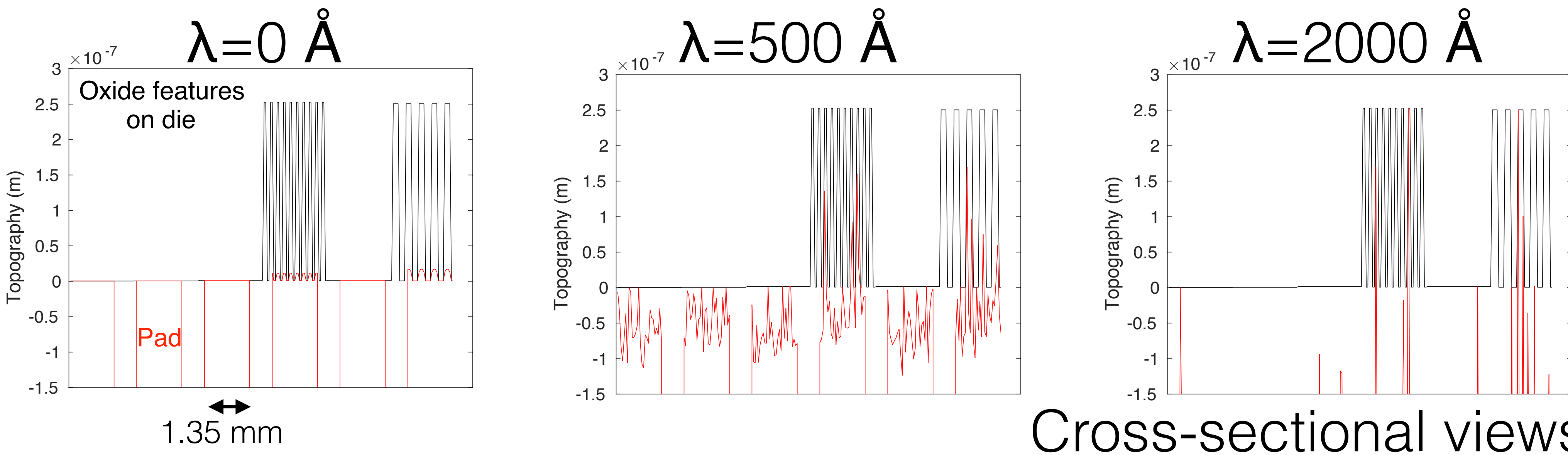

*error bars represent 95% confidence intervals on the mean
Lines: Simulations
Error bars: Experiments

# The model captures pad surface roughness effects



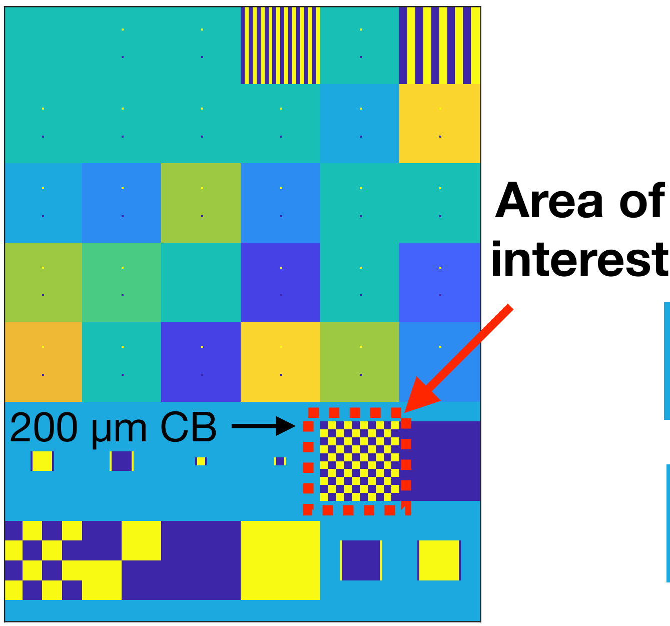

Top view

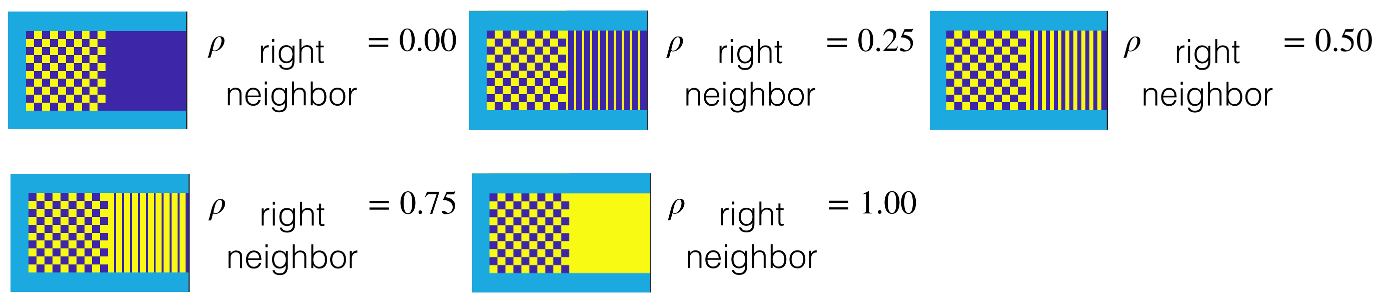



Cross-sectional views

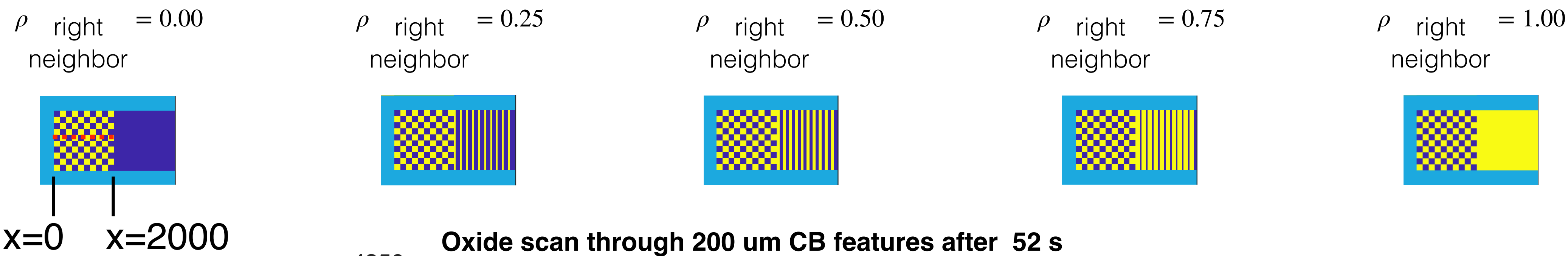
[6] Brian Salazar, Mayu Yamamura, Raghava Kakireddy, Shiyan Jayanth, Ashwin Chockalingam, Rajeev Bajaj, and Hayden Taylor, ”Die-scale modeling of planarization efficiency using segmented CMP pads: analyzing the effects of asperity topography” presented at the International Conference on Planarization/CMP Technology (ICPT), Hsinchu, Taiwan, September 2019.

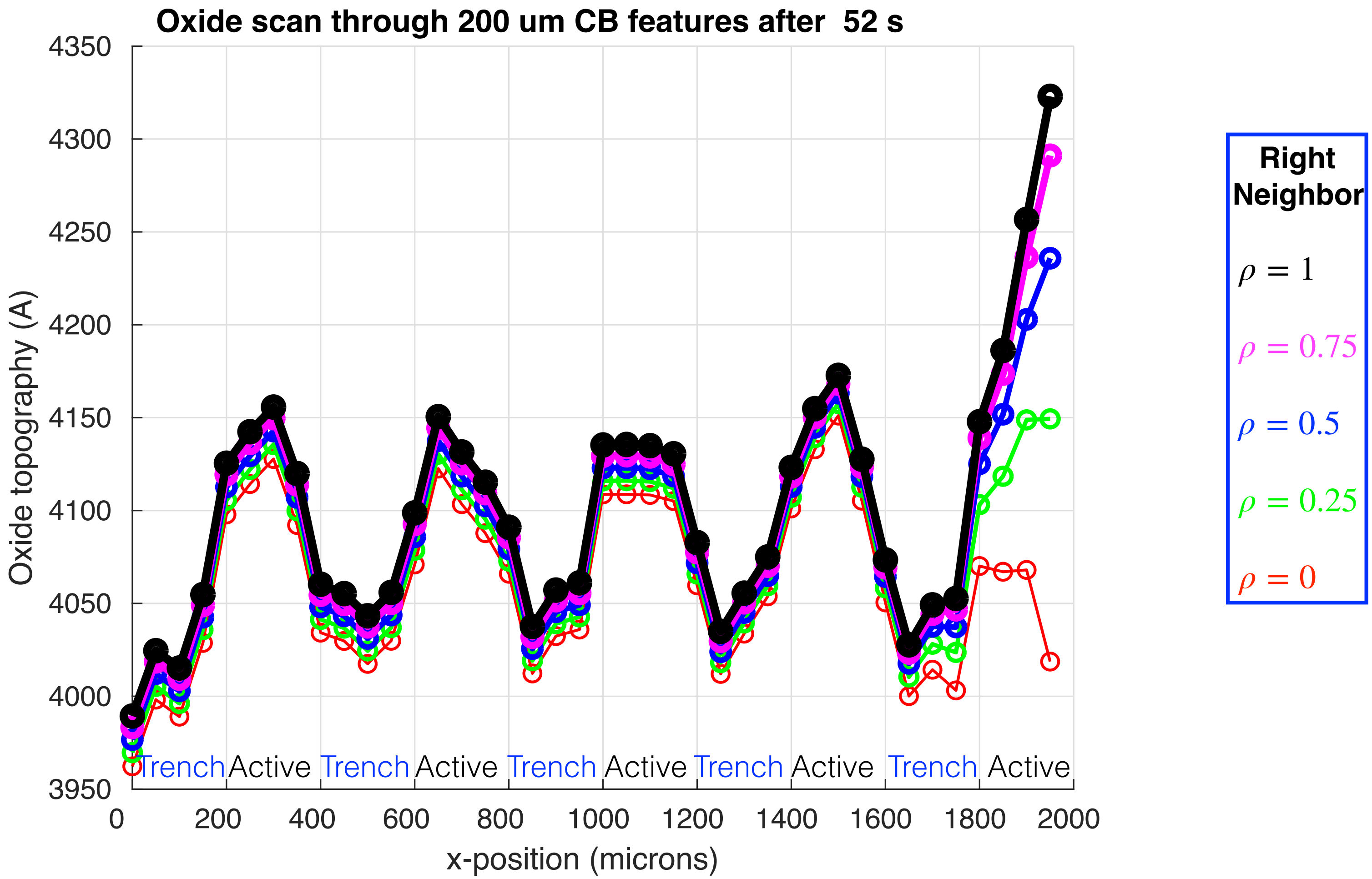
# We'll check sensitivity to the pattern design by varying the pattern density of the features directly to the right of the 200 µm checkerboards



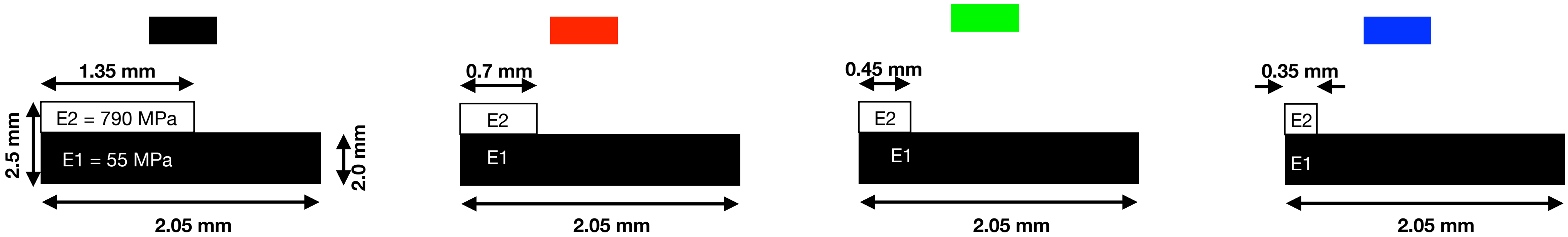



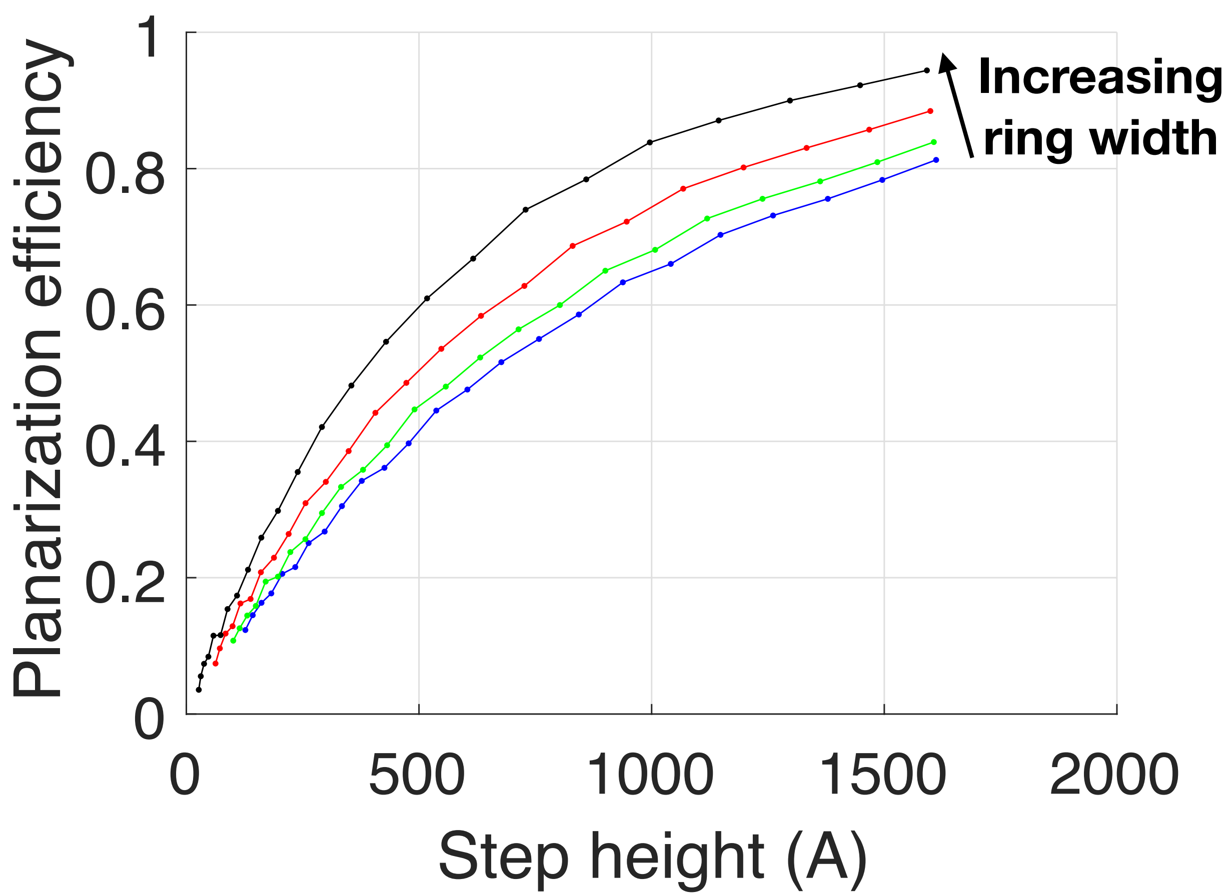
# The model is sensitive to the pattern density of neighboring features; we see differences of ~300 Å between the two extreme cases



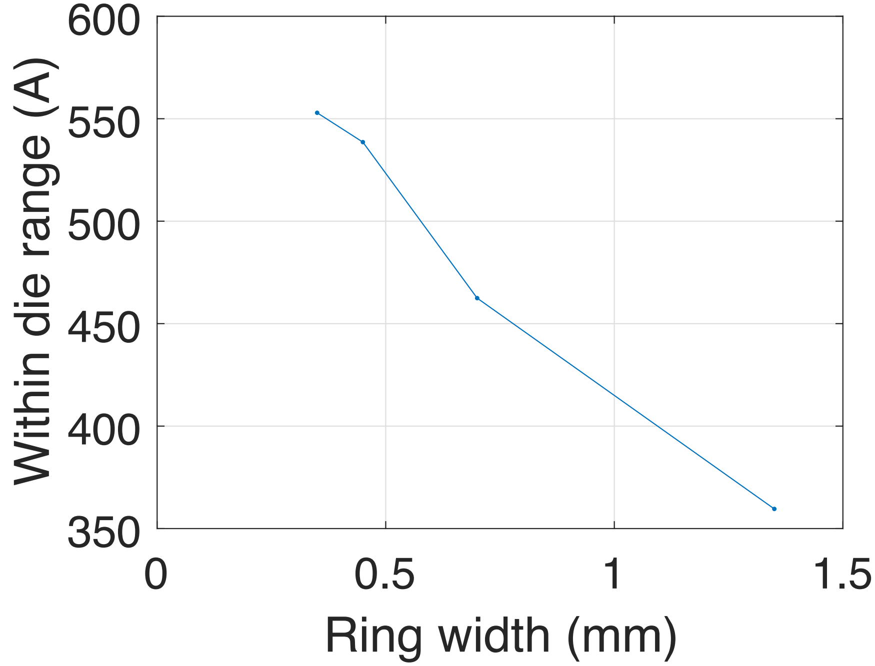



# The model accurately predicts that rings with larger widths have higher planarization efficiencies

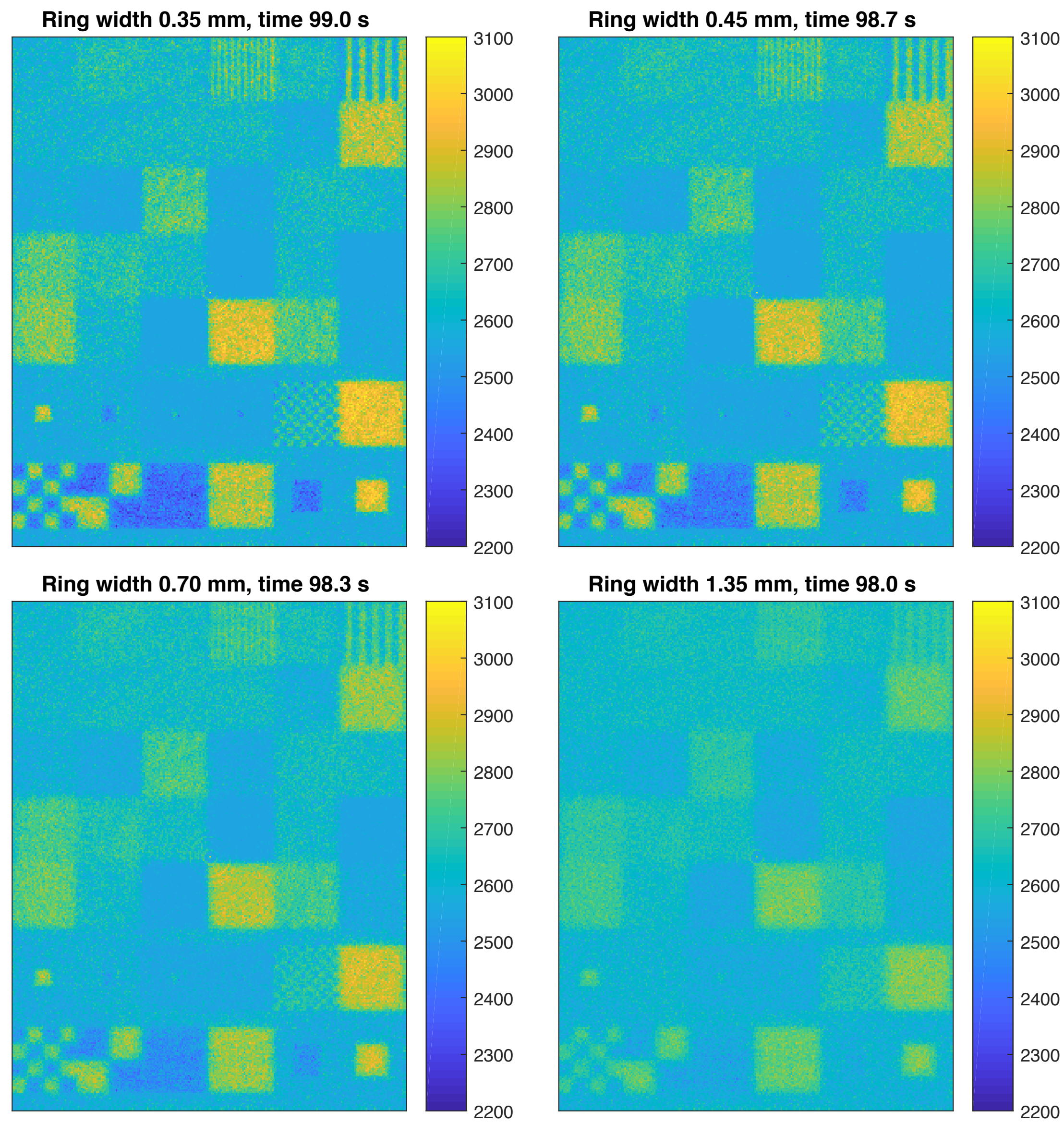


# Pads with larger ring widths have smaller within-die active oxide thickness ranges




**Topography (A)**




**Polish time is when the average active oxide thickness across the die is 100 Å**

# Conclusion and Contributions

- The die-scale contact wear model is able to capture trends in the removal rate as the die design is altered
- The neighborhood effect distance (planarization length) seems to be only a few millimeters, and is set by the asperity topography
- This is the only die-scale model that incorporates large, measured pad scans