ROHM AND HAAS ELECTRONIC MATERIALS
CMP TECHNOLOGIES

Advances in CMP Fundamental Understanding and Applications to Consumable and Process Design

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& A. Scott Lawing*

creating the **flawless** surface

Technology ▪ Consistency ▪ Productivity

Introduction

- Contact Area Measurement and Modeling
  - Fundamental understanding
    - Ex: Sub-pad effect
  - Rational consumable design
    - Ex: Low Stress Polishing
- Process Fundamentals: Backmixing
  - Backmixing criteria
  - Backmixing process response
    - Uniformity
    - Defectivity
  - Pattern transfer
- Pad & Conditioning Process Design: VisionPad™5000 Polishing Pad for STI

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Contact Area Measurement and Modeling

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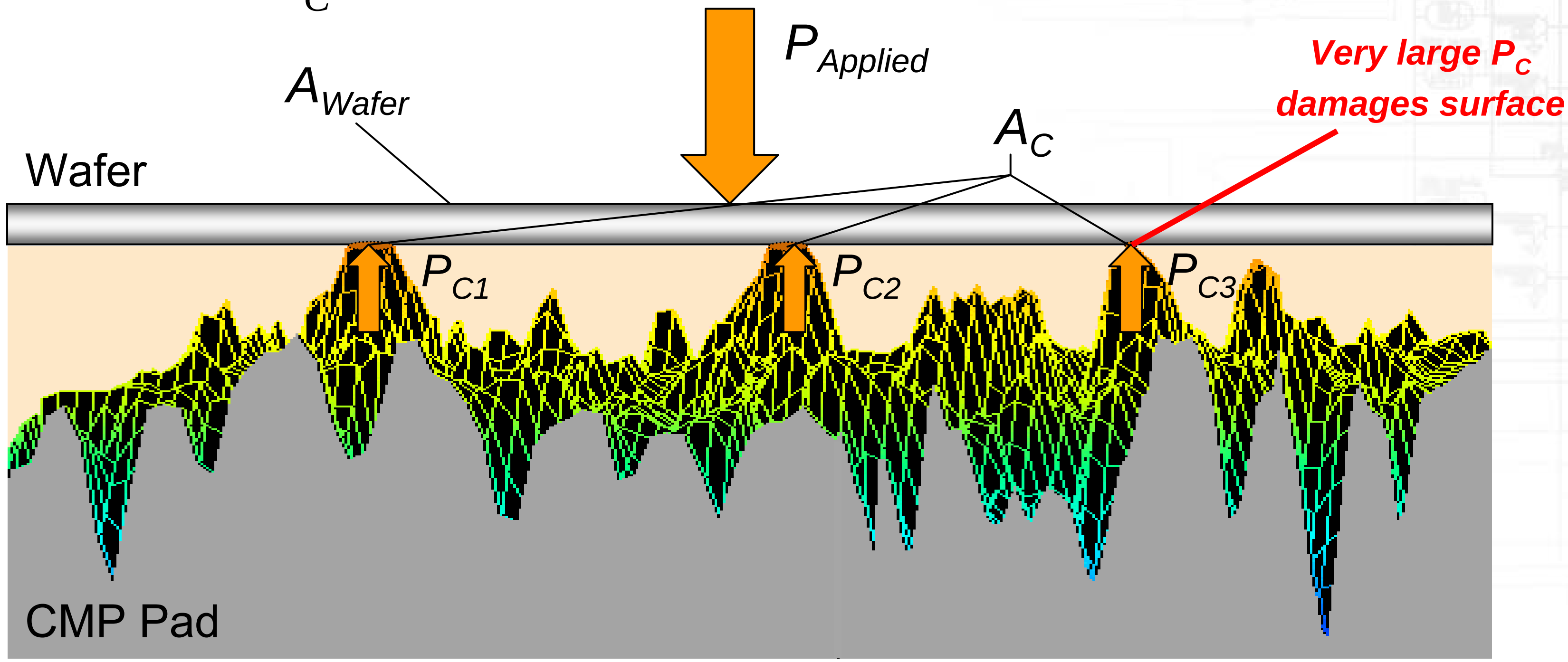
Point Contact Area and Pressure

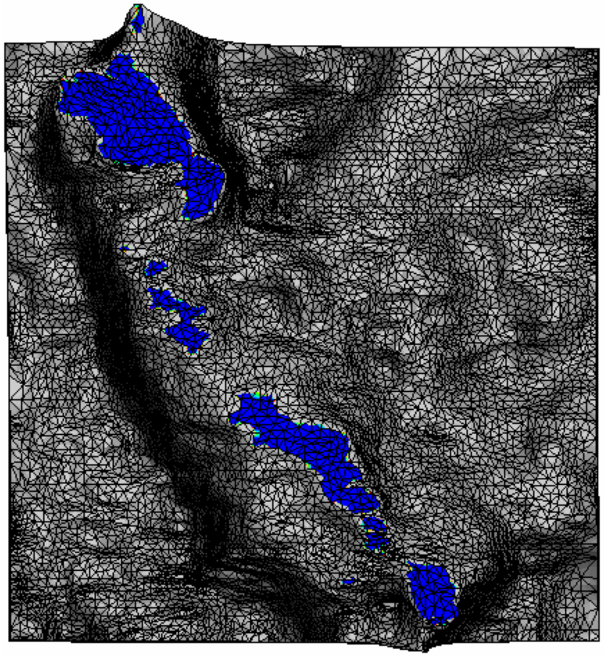
- Elimination of defects is more effectively achieved by elimination of high *contact pressures*

$$\overline{P}_C = \frac{P_{Applied}}{A_C} \qquad A_C << A_{Wafer} \qquad \therefore P_C >> P_{Applied}$$

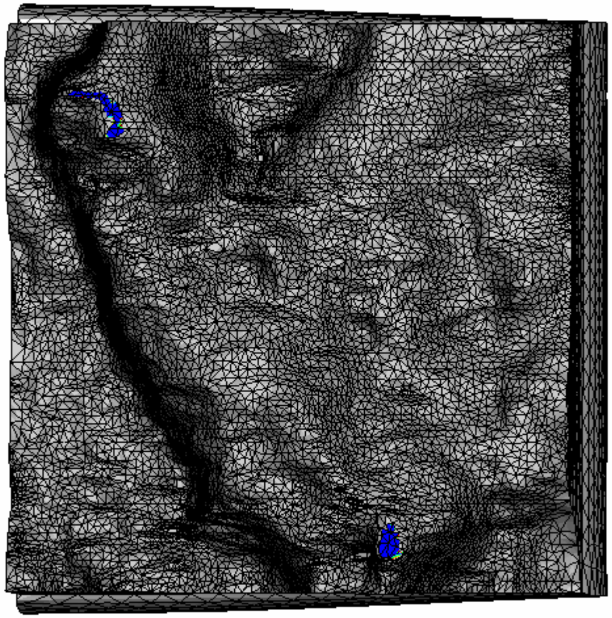


- Breakthrough increases in pad-wafer contact area will reduce defects even with no change in applied downforce or coefficient of friction

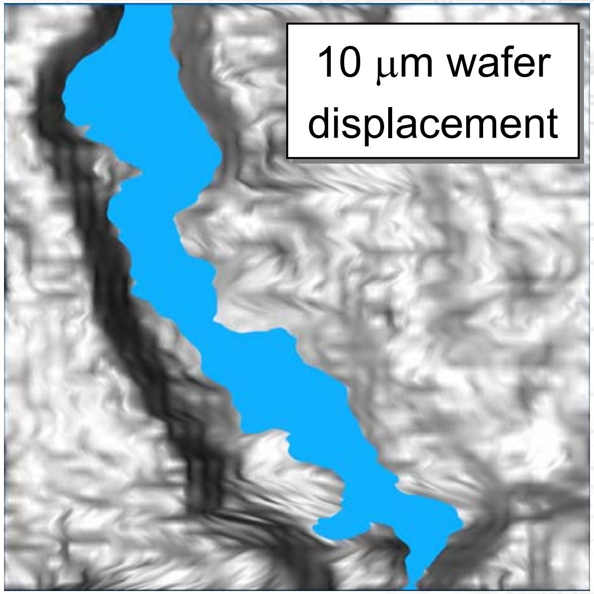
Contact Shape vs. Cross-Section



Simulated Contact Shape: Top Pad Only



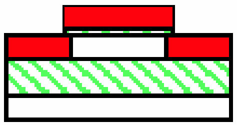
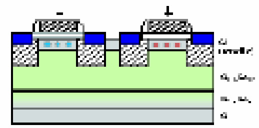
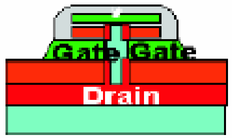
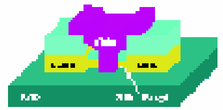
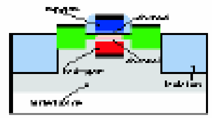
Simulated Contact Shape: Top Pad + Sub-Pad

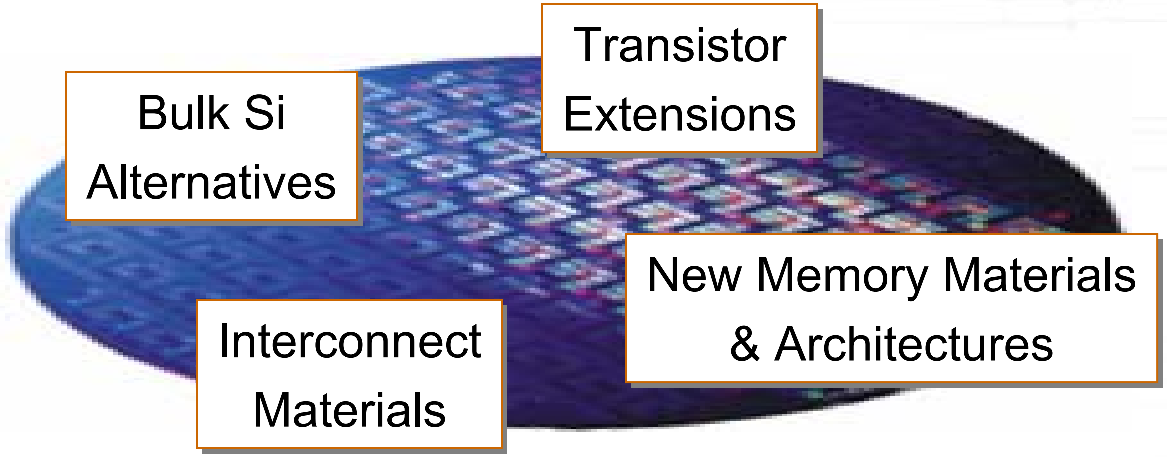


Cross-Sectional Area

- Difference between contact area and cross-section is observed at all scales
- Difference between contact area and cross-section is strikingly larger when a sub-pad absorbs most of the displacement

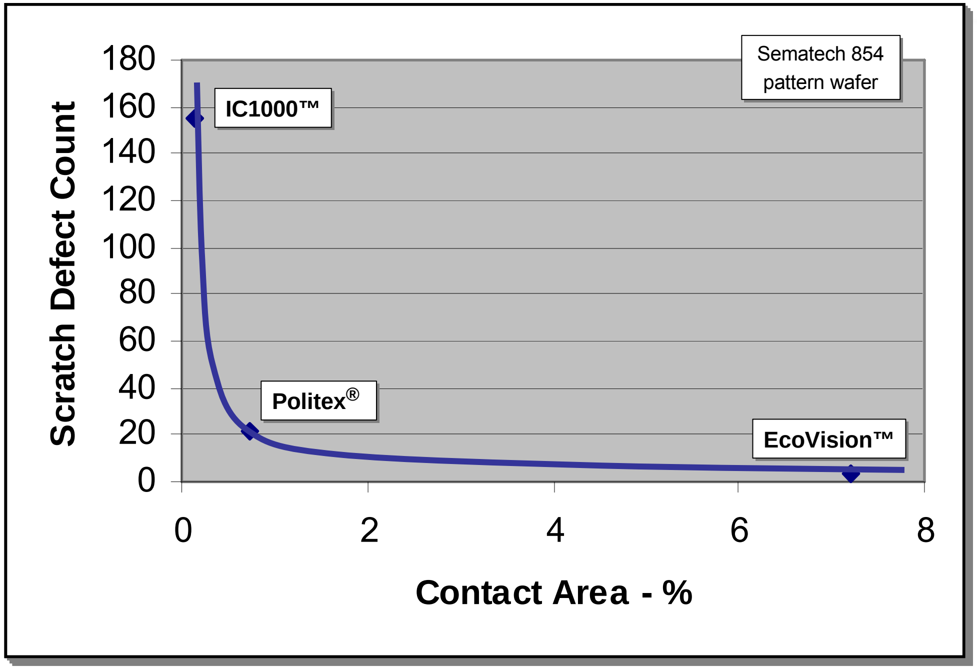
Low-Stress CMP for Emerging Devices

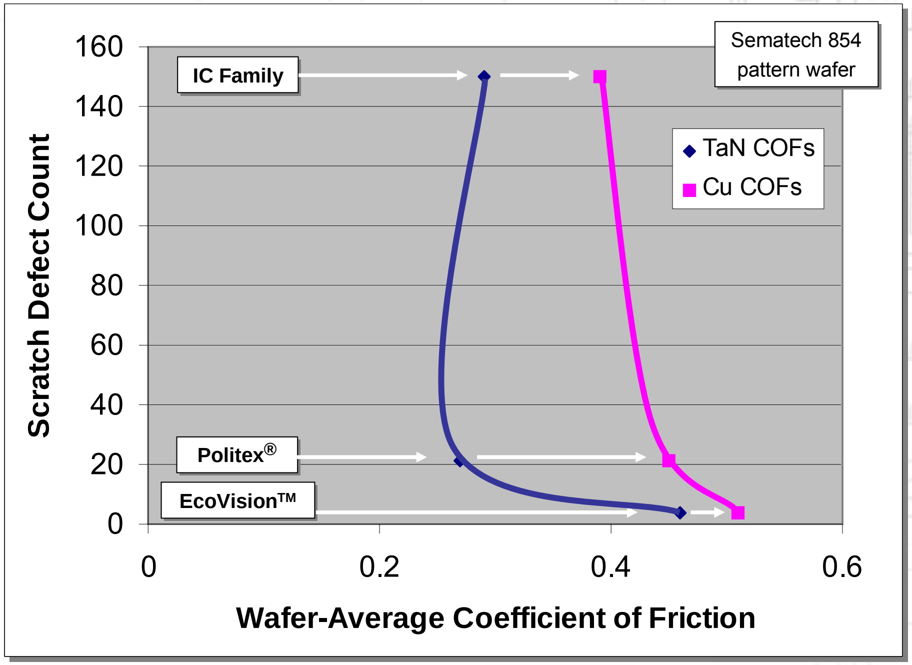
				
ULTRA-THIN BODY SOI	BAND-ENGINEERED TRANSISTOR	VERTICAL TRANSISTOR	FINFET	DOUBLE-GATE TRANSISTOR



- New materials to planarize → Novel slurry chemistries
- Unforgiving error budgets → Wafer-scale pad flatness
- Fragile device structures → Low-stress planarization
- Low defect tolerance → *Low-stress planarization!*

Contact State Determines Defectivity



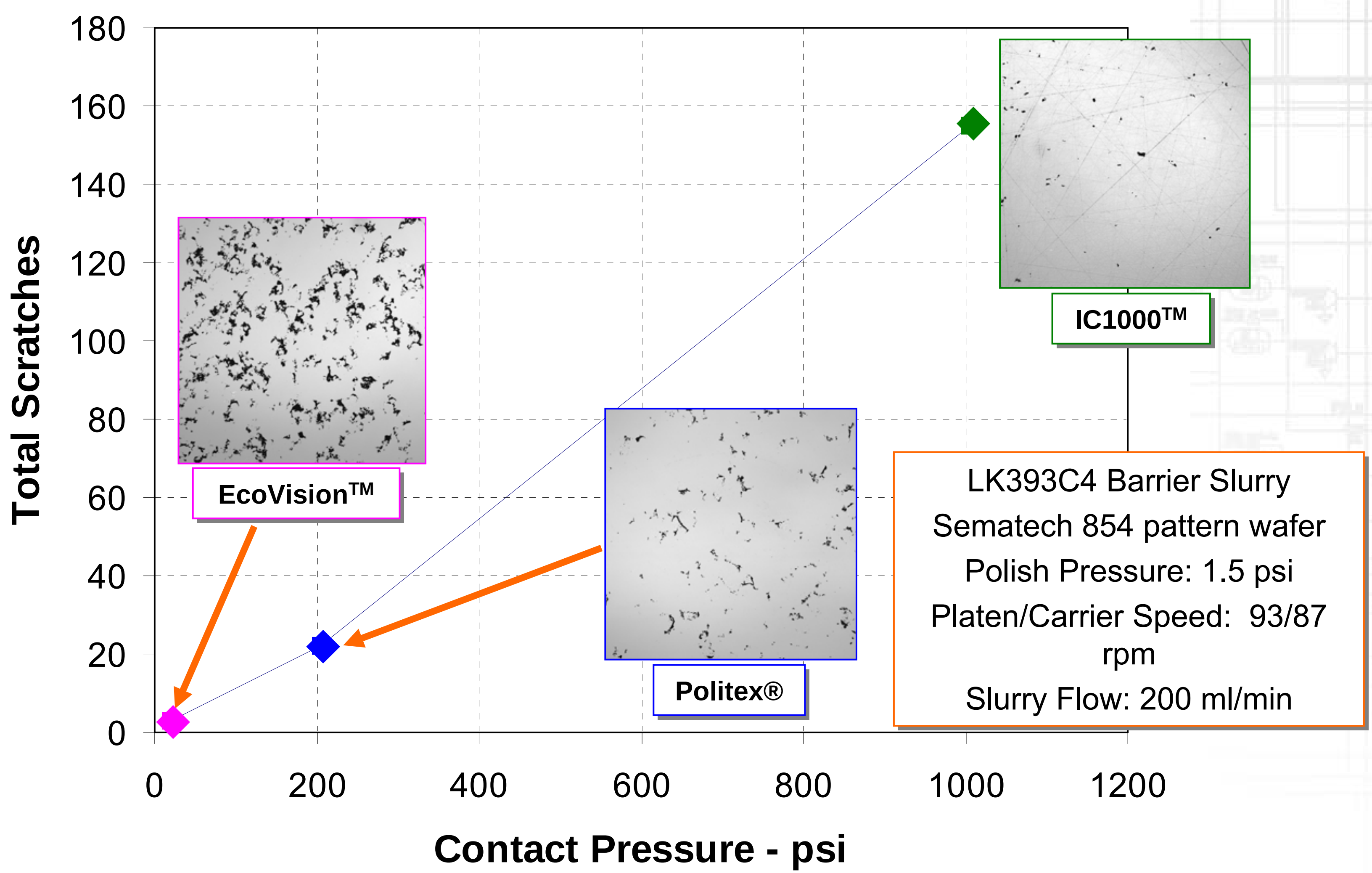


Scratch Defect Counts in Cu Barrier CMP at 1.5 psi

AMAT Mirra® Polisher, 93/87 rpm, LK393C4 slurry

- Defects approach zero as contact pressure drops to same order of magnitude as applied pressure
- There is no general trend of lower defects at lower COF across pad types

CMP Defects vs. Contact Pressure



- Point contact pressure has emerged as a key driver of scratch defects
- High-contact pads are an ongoing R&D focus to provide low-stress polish

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Process Fundamentals: Backmixing

Muldowney

(Additional data by Lawing)

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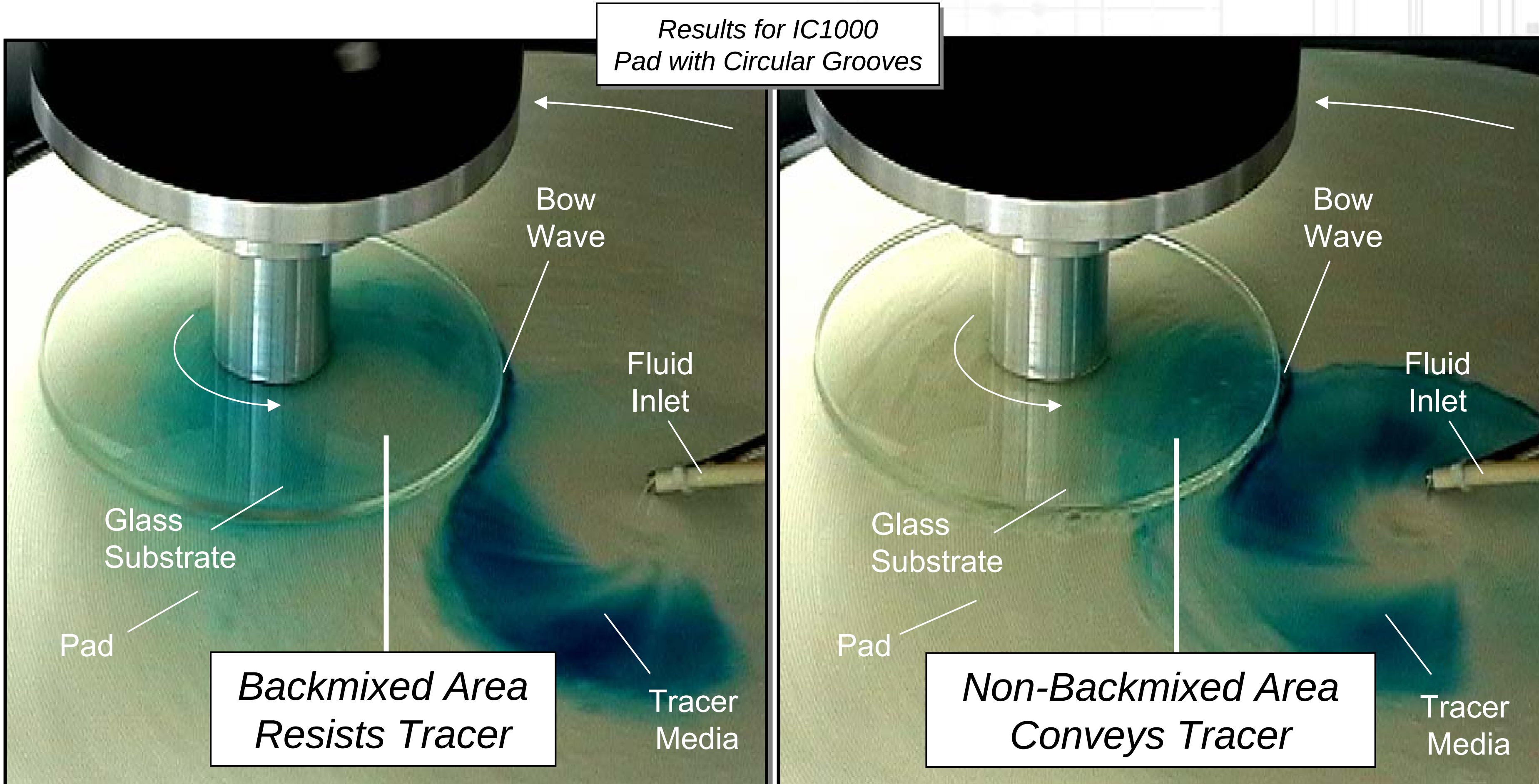
Backmixing Effect in CMP Tracer Experiments



- Backmixed region resists fresh slurry influx for many wafer rotations
- Non-backmixed condition conveys slurry across full wafer track

Slurry Backmixing Criteria

- Backmixing affects wafer over width *w** at edge:

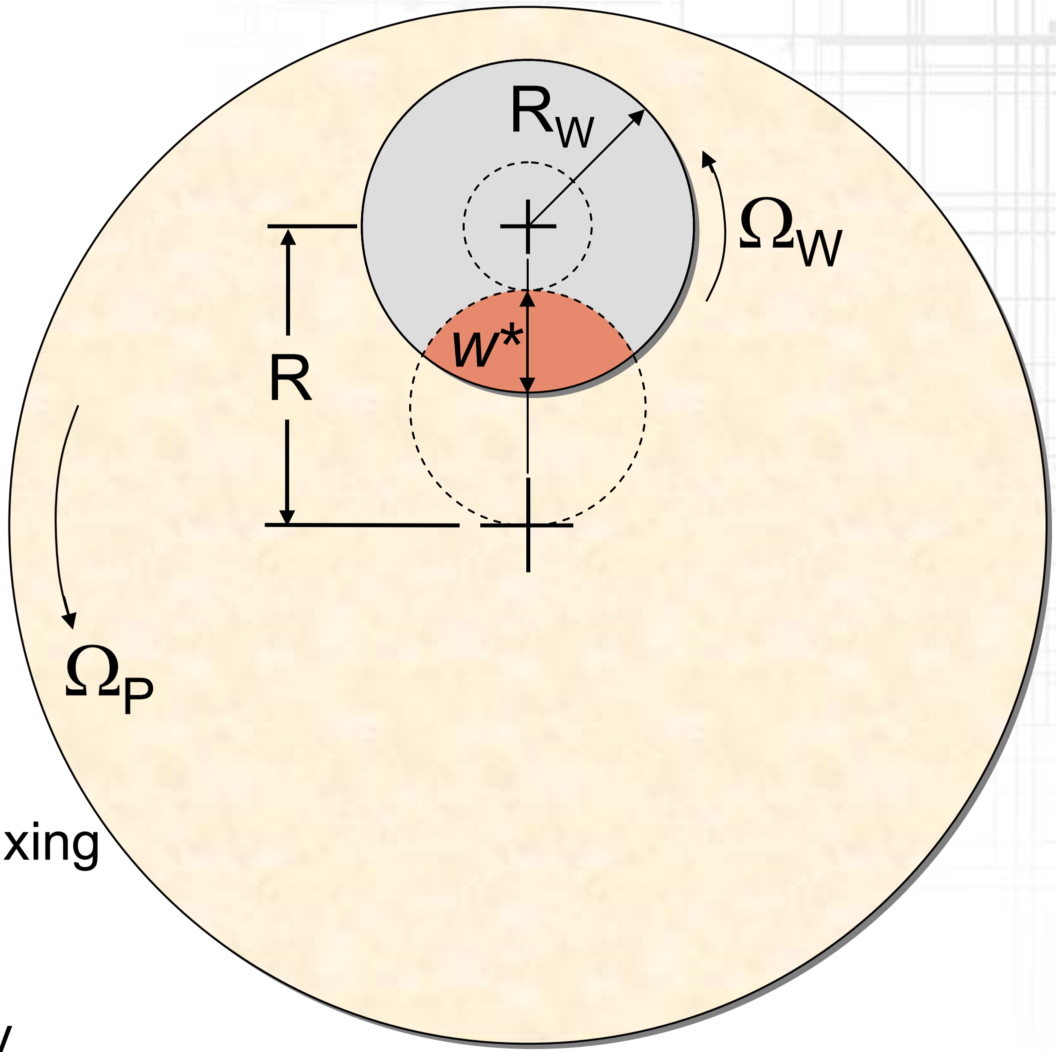
$$w^* = R_W - \frac{R}{1+\frac{\Omega_W}{\Omega_P}}$$

- For wafer to be unaffected by backmixing (*w* = 0*):

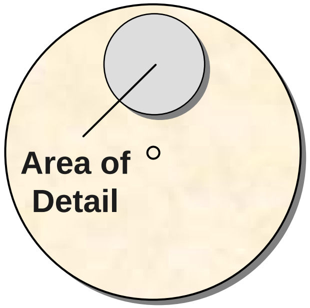
$$\Omega_W \le \Omega_P\left(\frac{R-R_W}{R_W}\right)$$

- For R_W/R of 0.7-0.8, need $\Omega_P/\Omega_W > 2.5$ to avoid backmixing

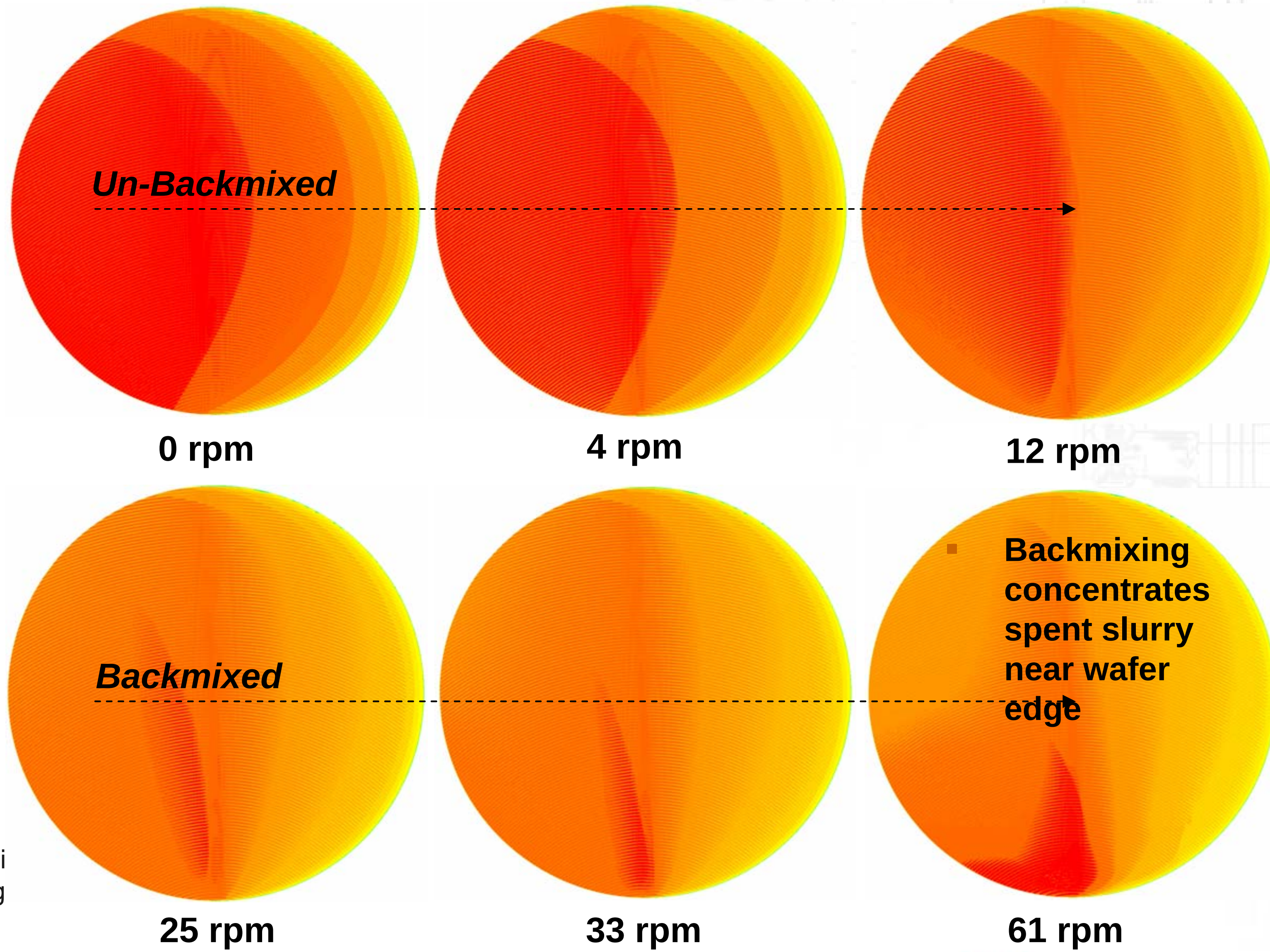
- Larger wafers (higher R_W/R) make backmixing more likely and affected width *w** greater



Effect of Backmixing on Steady-State Concentration Field

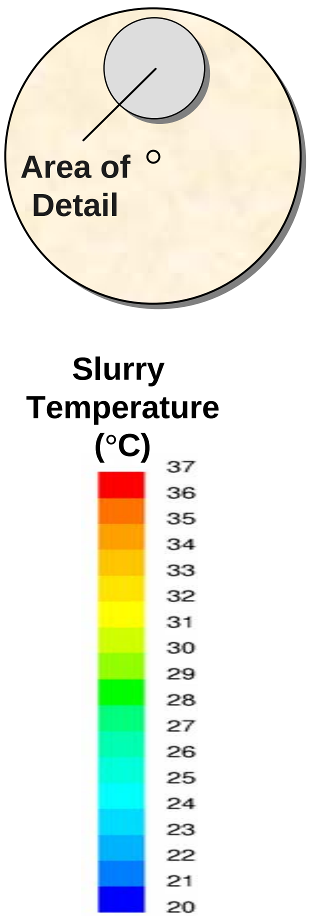


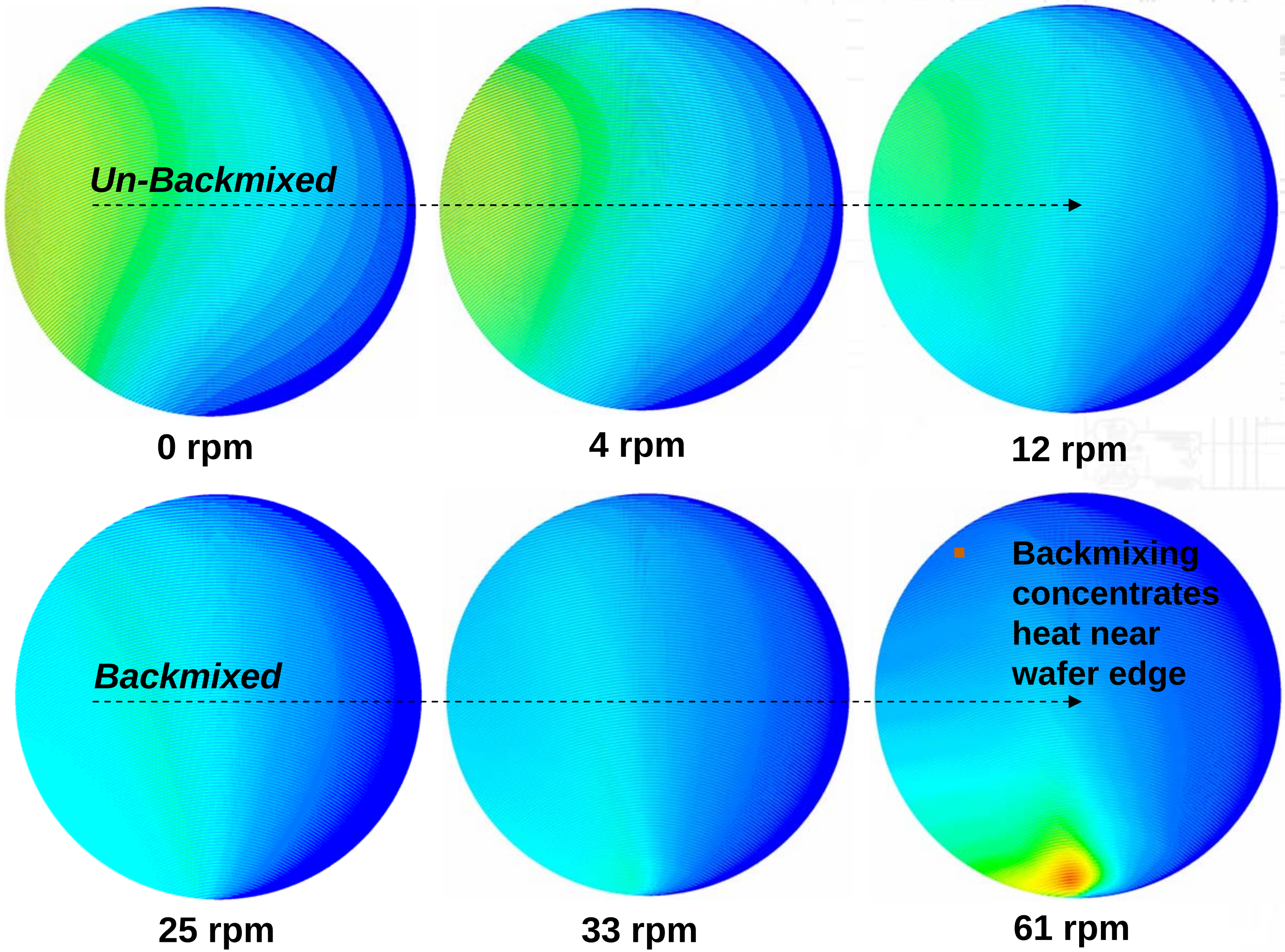
Mass Fraction
Spent Slurry



Case:
Pad 33 rpm
Polish Pressure 3 psi
Medium Conditioning
Flat 43 μm Gap
Wafer Surface

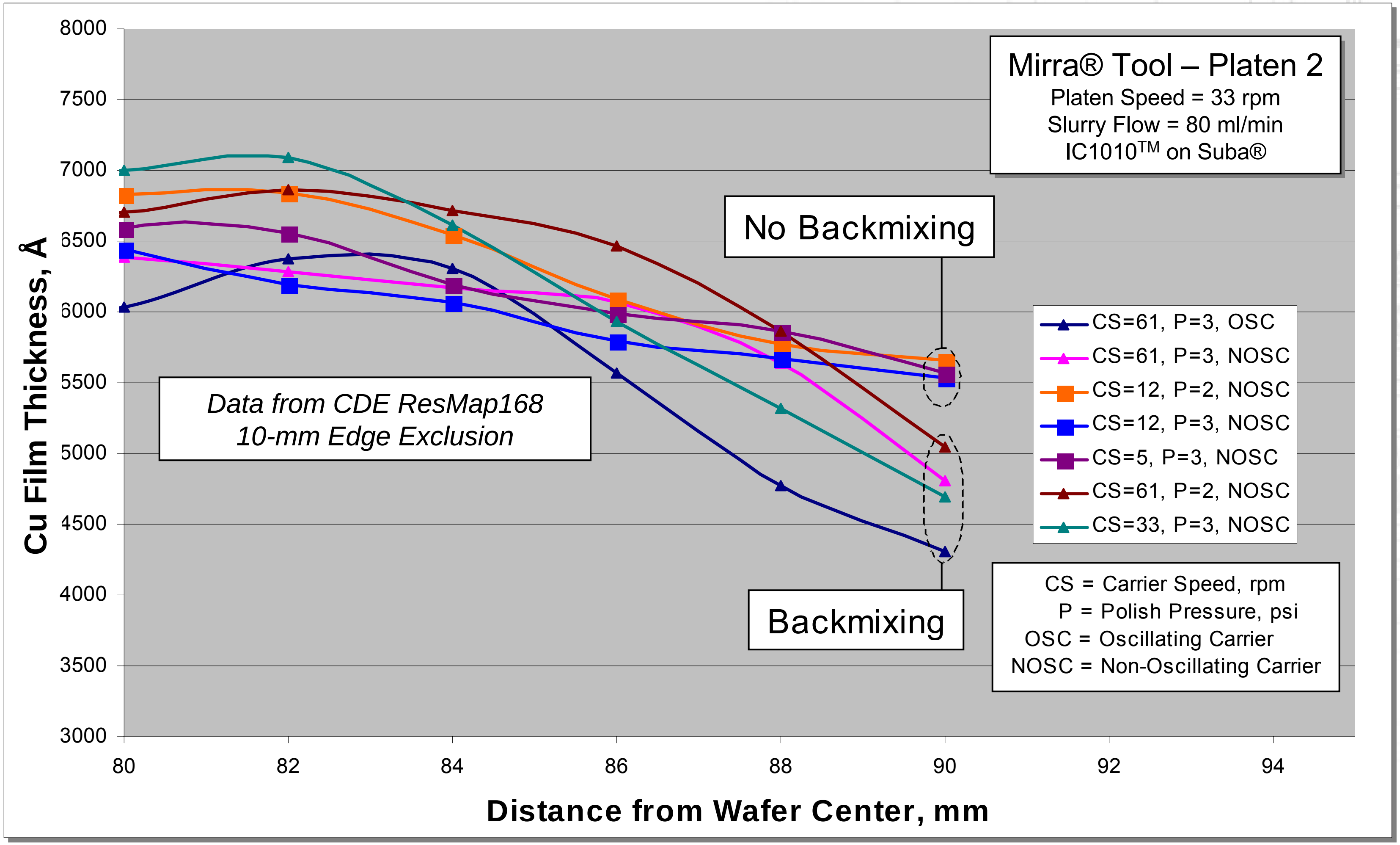
Effect of Backmixing on Steady-State Temperature Field





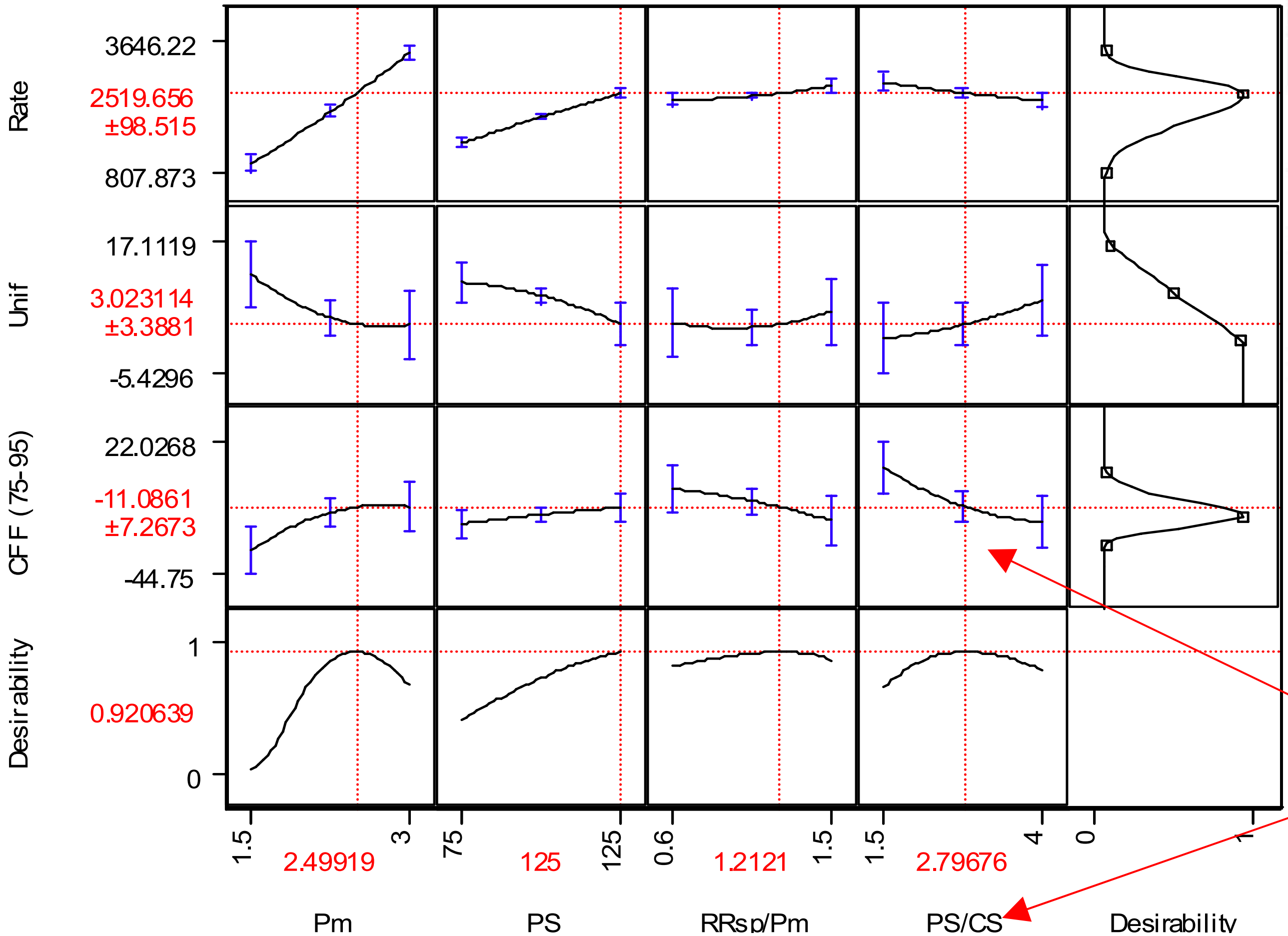
Case:
Pad 33 rpm
Polish Pressure 3 psi
Medium Conditioning
Flat 43 μm Gap
Wafer Surface

Effect of Backmixing on Wafer Edge Profiles



- No-backmixing improved edge profiles regardless of polish pressure
- Reflects more consistent transport in absence of reverse slurry flow

Effect of Backmixing on Uniformity Optimization

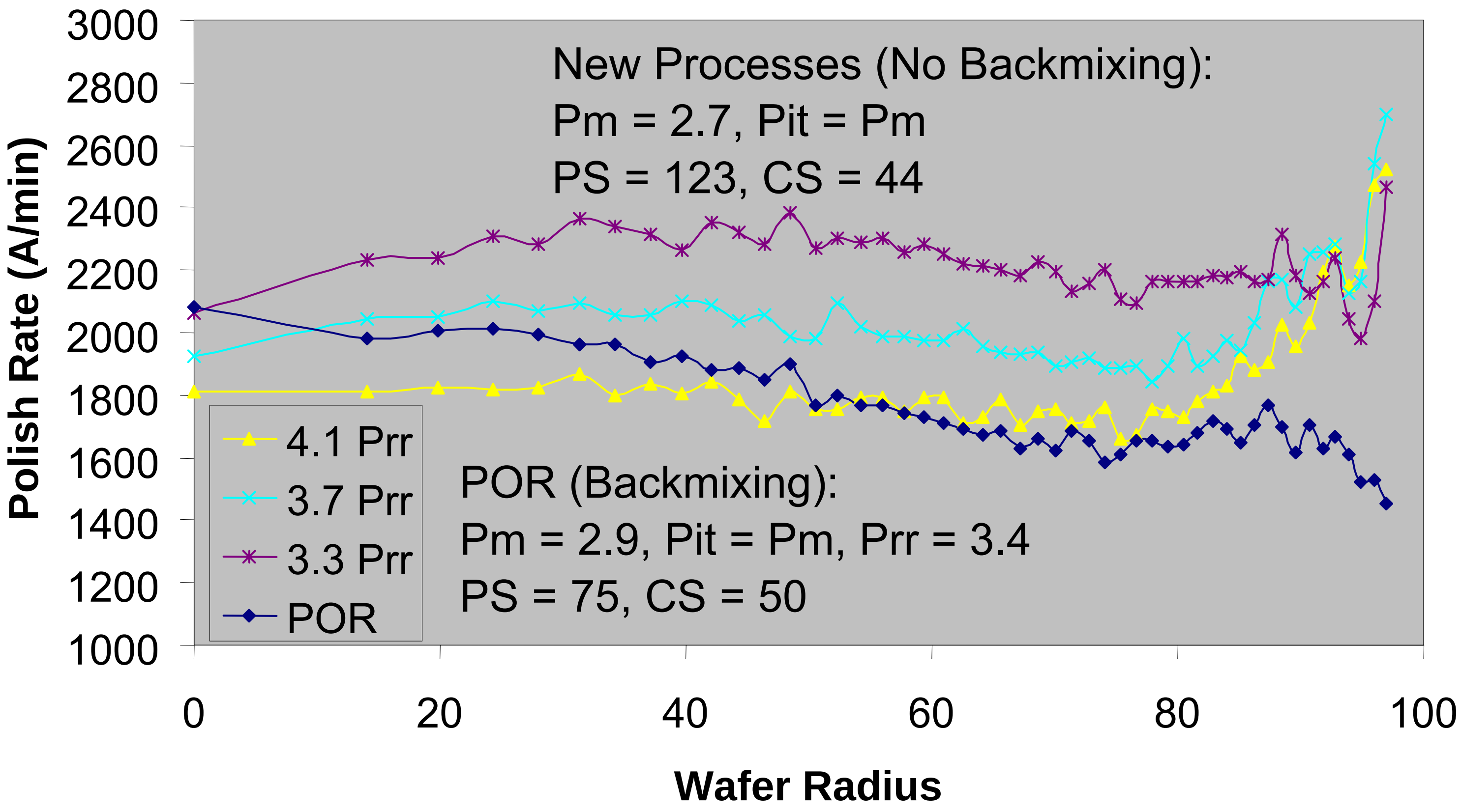


Desirability functions indicate one way to optimize the process based on the results of the DOE.

In this case targets for rate and profile (Center Fast Factor) were input and uniformity (% σ) was minimized

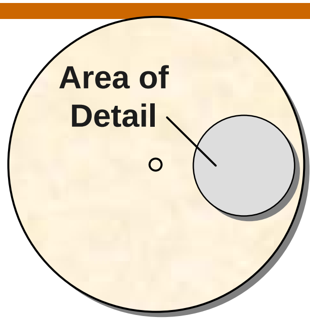
Note that increasing PS/CS drives CFF down (*i.e.* more center slow!)

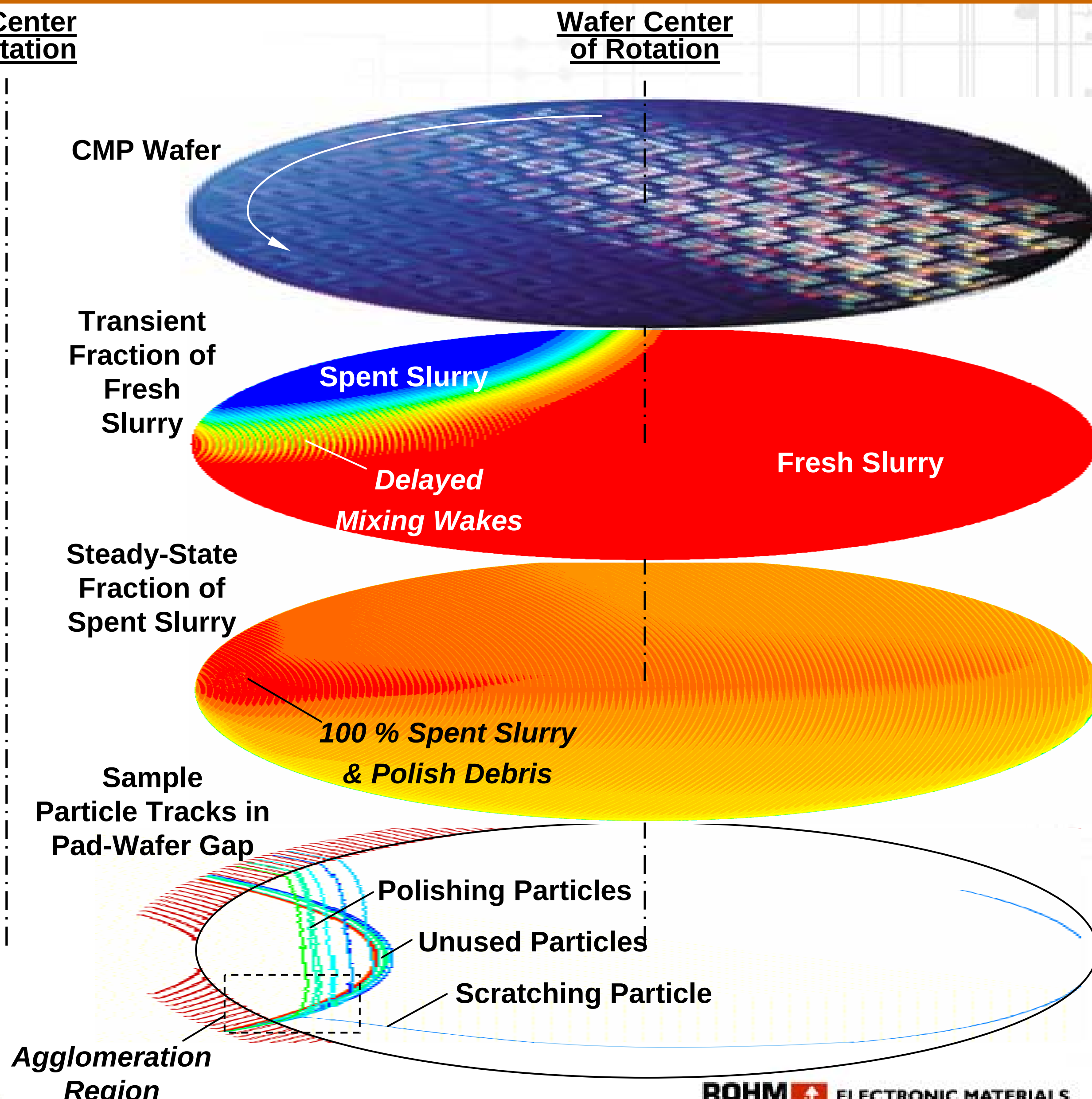
Effect of Backmixing on Uniformity Optimization



- More control is obtained over center-to-edge profile at high platen speed/carrier speed ratio

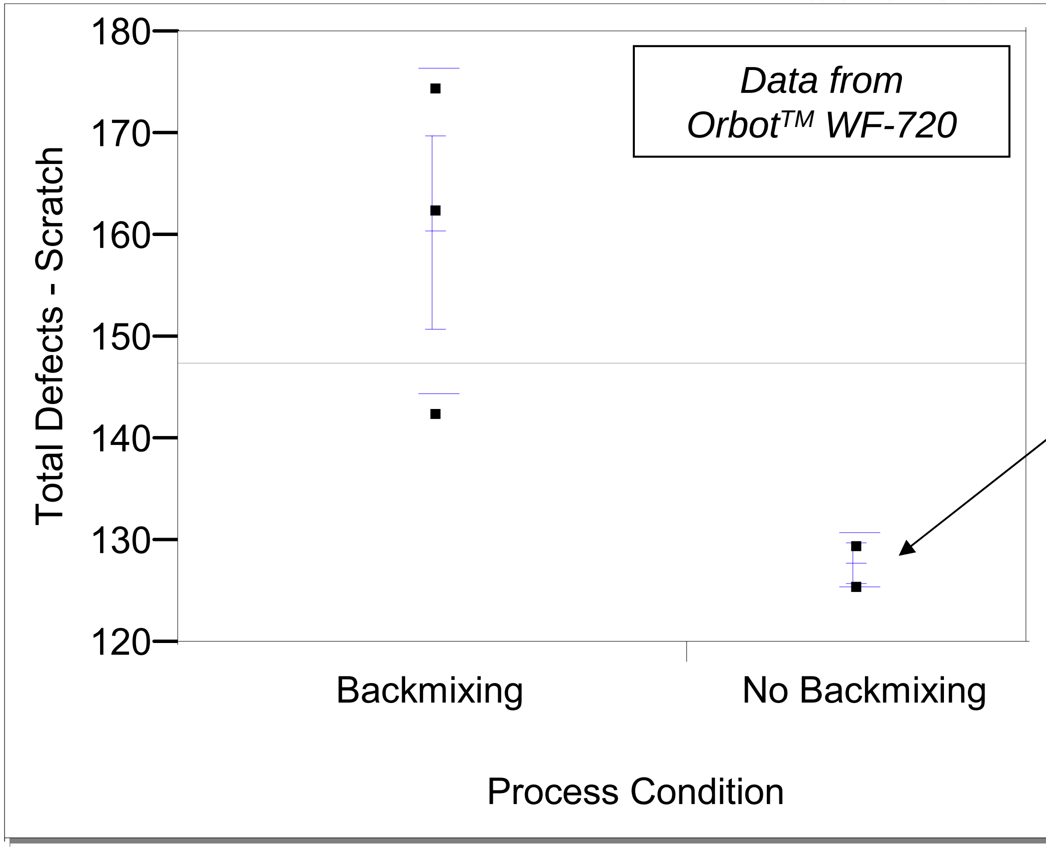
Origins of Scratch Defects





- Slurry renewal is slow near pad center due to reverse motion of wafer, allowing debris to collect and recycle
- Agglomerated debris and particles ejected from groove may inflict scratch defects
- Spiral grooves renew slurry more effectively at pad center to arrest this defect mechanism

Effect of Backmixing on Cu Defectivity

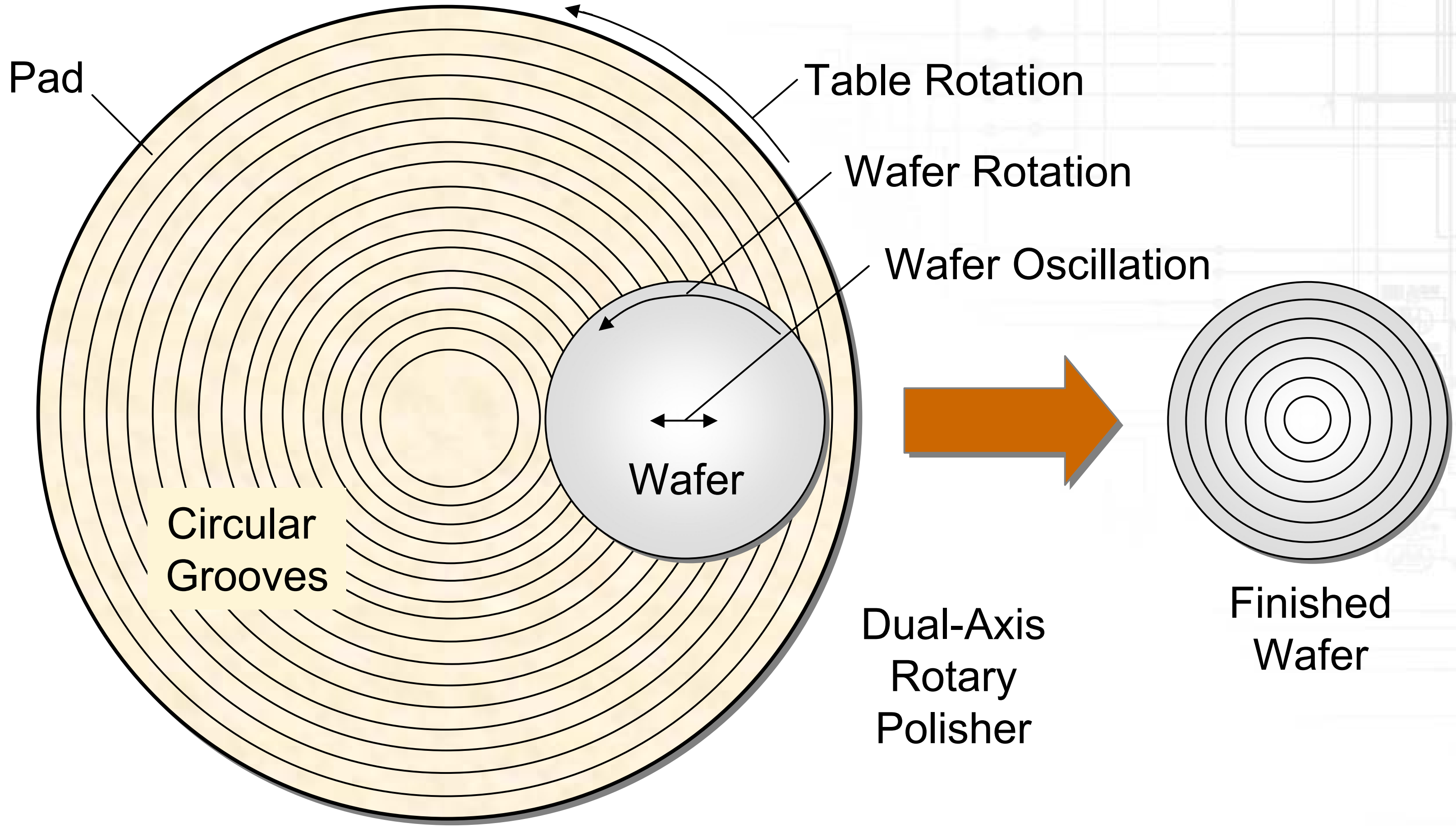


Mirra® Tool – Platen 2
Platen Speed = 33 rpm
Slurry Flow = 80 ml/min
IC1010TM on Suba®

$$\frac{\Omega_W}{\Omega_P} \leq \left(\frac{R}{R_W} - 1\right)$$

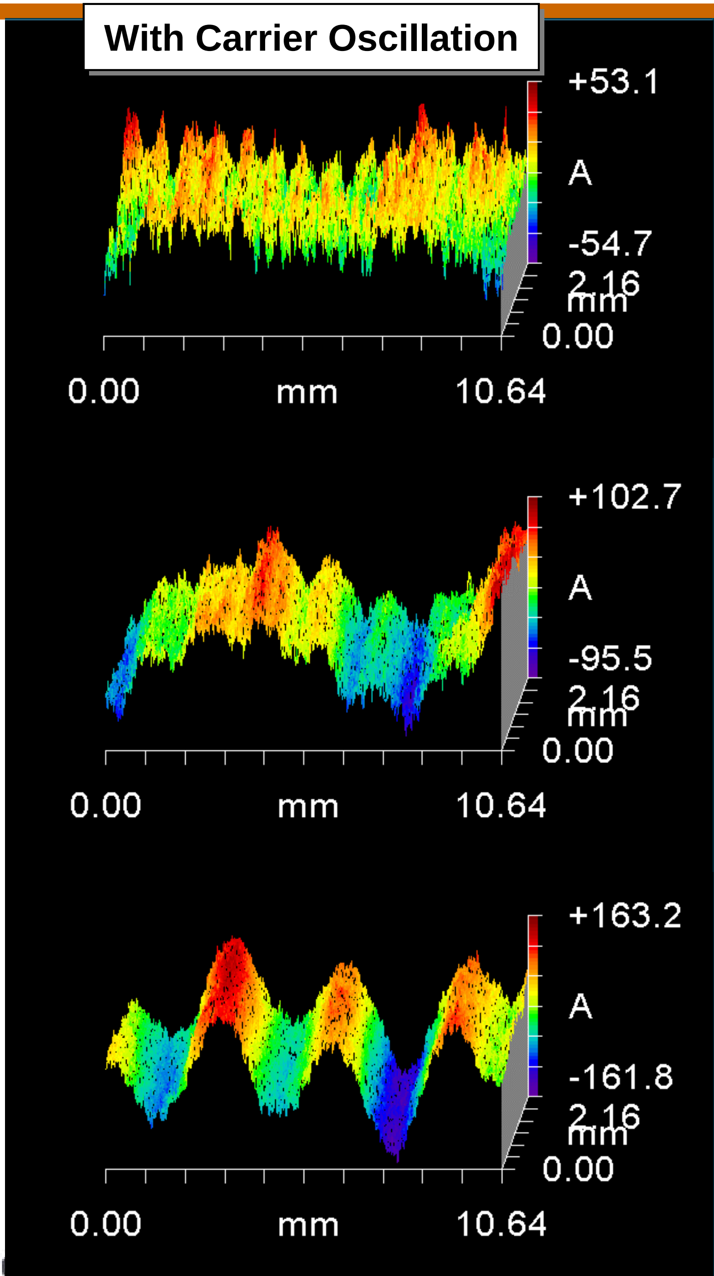
- No-backmixing improved defect counts by 25% at 3 psi pressure
- Pad rotation conveys away spent particles and polish debris faster than wafer rotation can recapture them

Groove Pattern Transfer



- Rotation/oscillation exposes point on wafer to many points on pad
- Off-center position exposes wafer to all angles with respect to pad surface and grooves
- Despite motions, wafer is imprinted with rings *matching groove pitch*

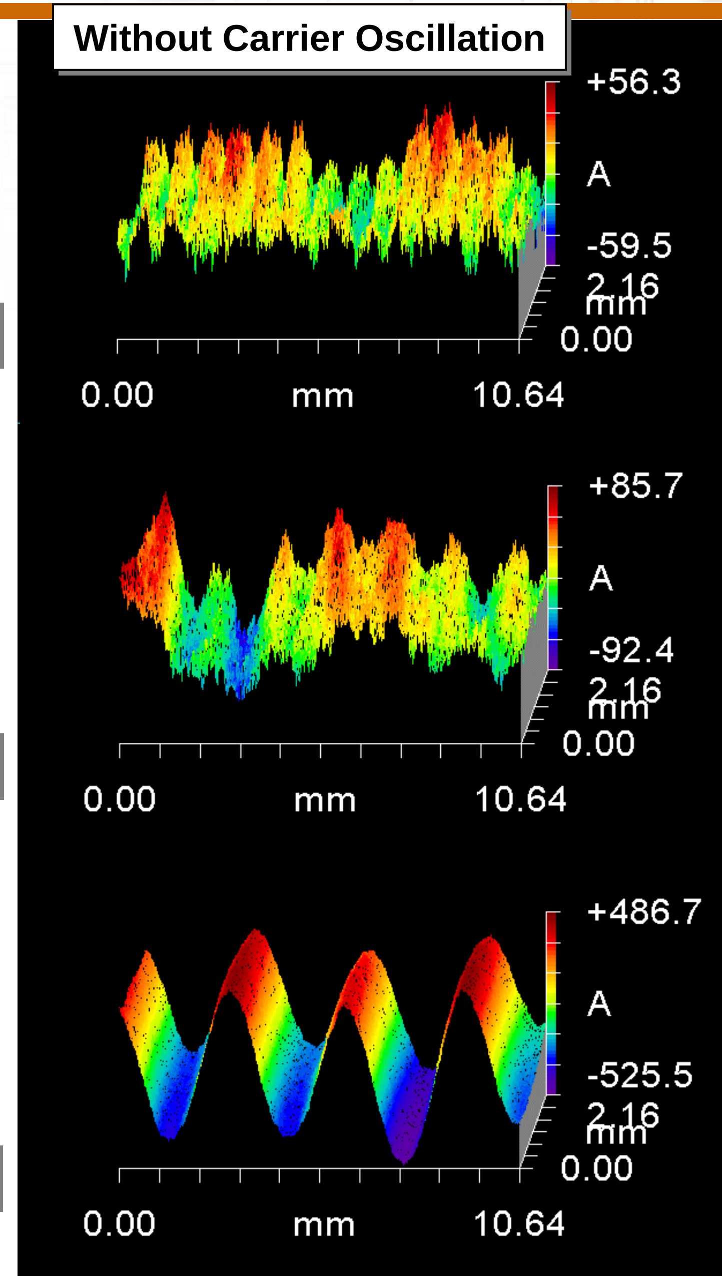
Porous IC1000™ Pad



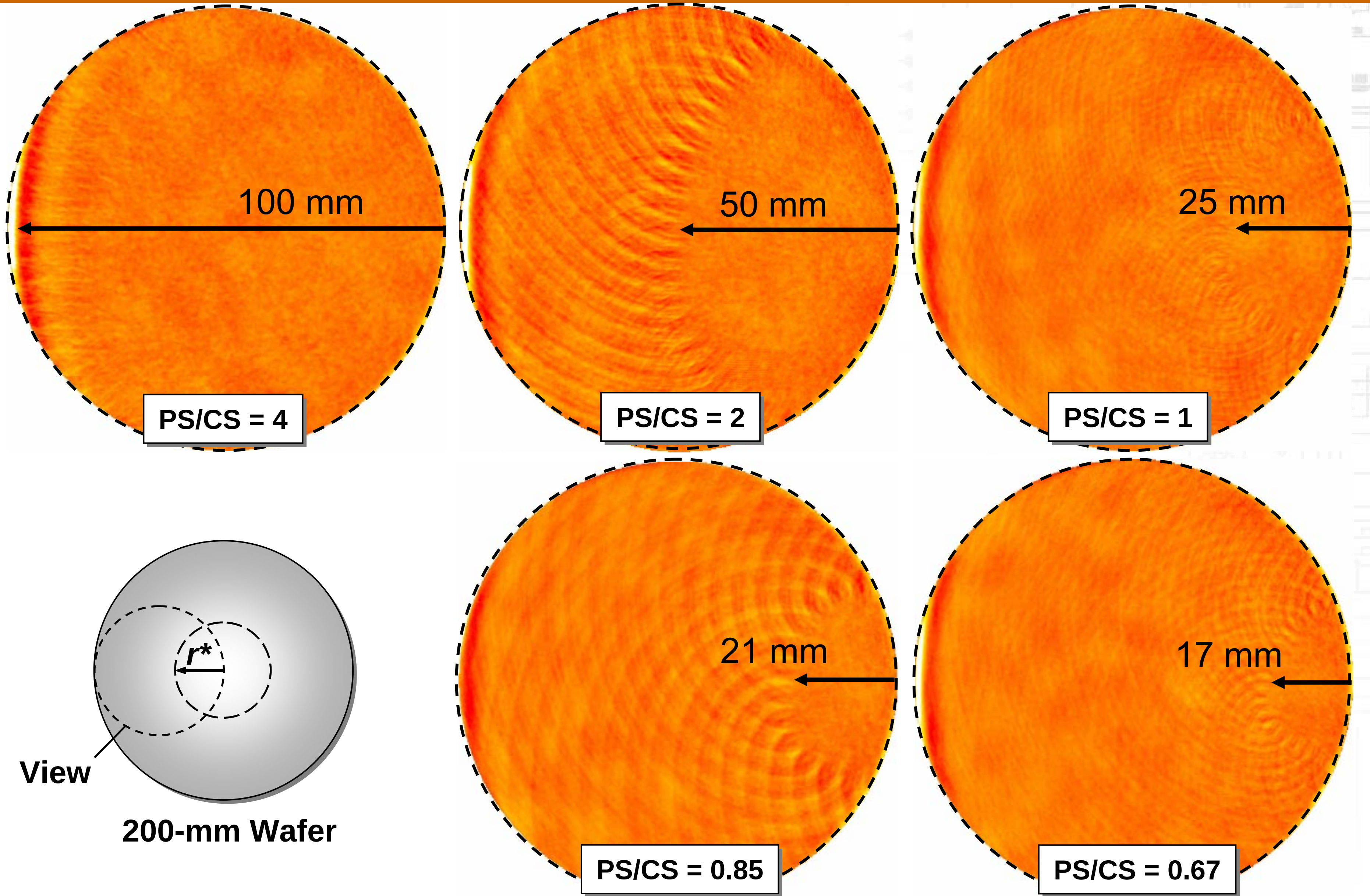
0.030" Pitch

0.060" Pitch

0.120" Pitch



Effect of Backmixing on Pattern Transfer



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Pad Conditioning & Process Design: VisionPad™ 5000 for STI

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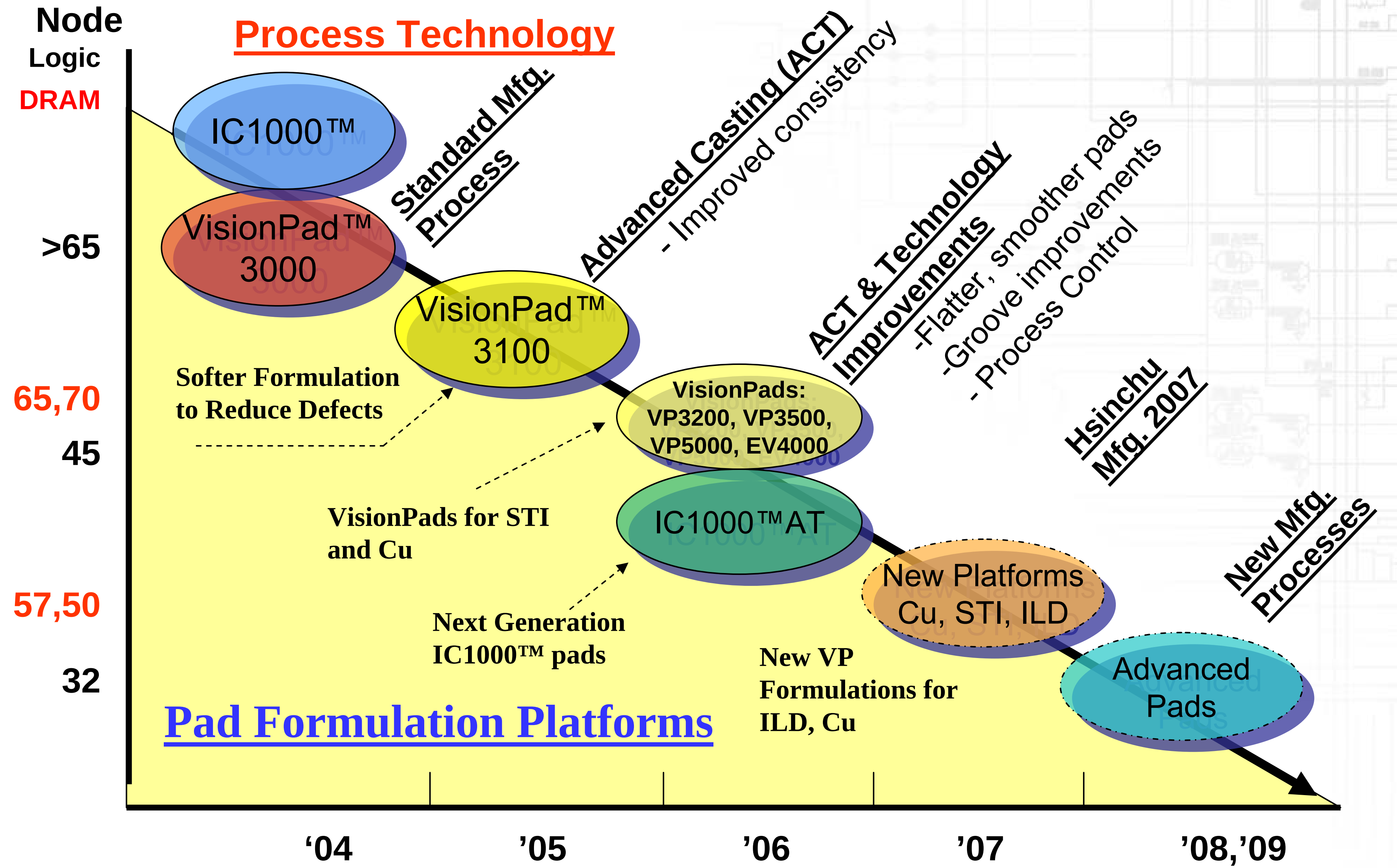
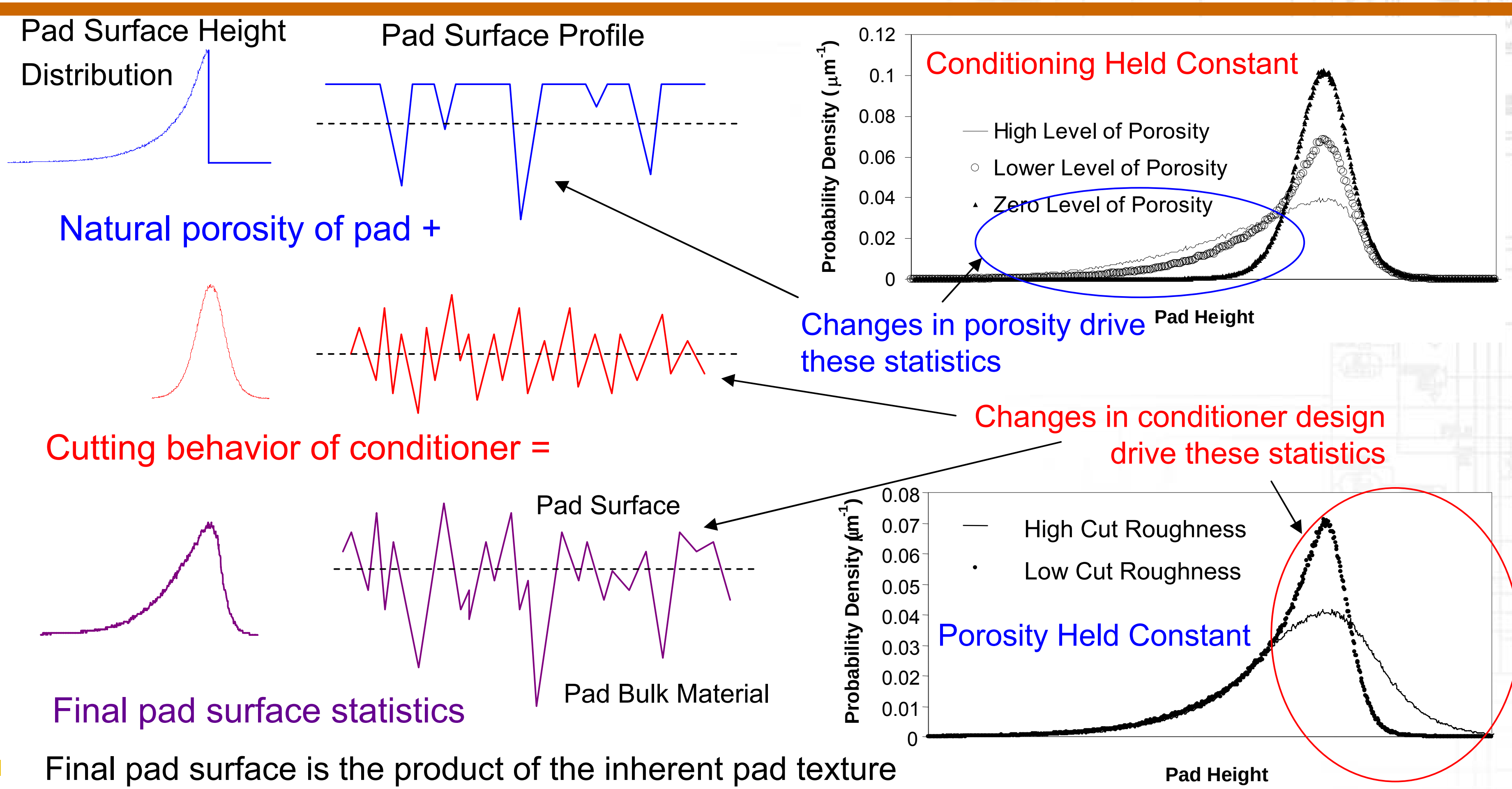
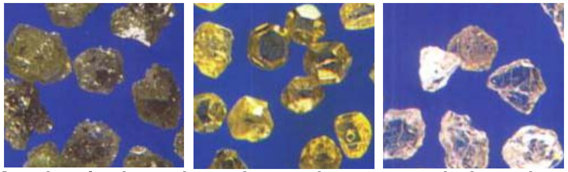

Node
Logic
DRAM
Process Technology
IC1000™
VisionPad™ 3000
VisionPad™ 3100
Standard Mfg. Process
Advanced Casting (ACT)
- Improved consistency
ACT & Technology Improvements
-Flatter, smoother pads
-Groove improvements
- Process Control
Hsinchu Mfg. 2007
New Mfg. Processes
VisionPads: VP3200, VP3500, VP5000, EV4000
IC1000™AT
New Platforms Cu, STI, ILD
Advanced Pads
>65
65,70
45
57,50
32
Softer Formulation to Reduce Defects
VisionPads for STI and Cu
Next Generation IC1000™ pads
New VP Formulations for ILD, Cu
Pad Formulation Platforms
'04
'05
'06
'07
'08,'09

Conditioner Design, Natural Porosity & Pad Texture Evolution

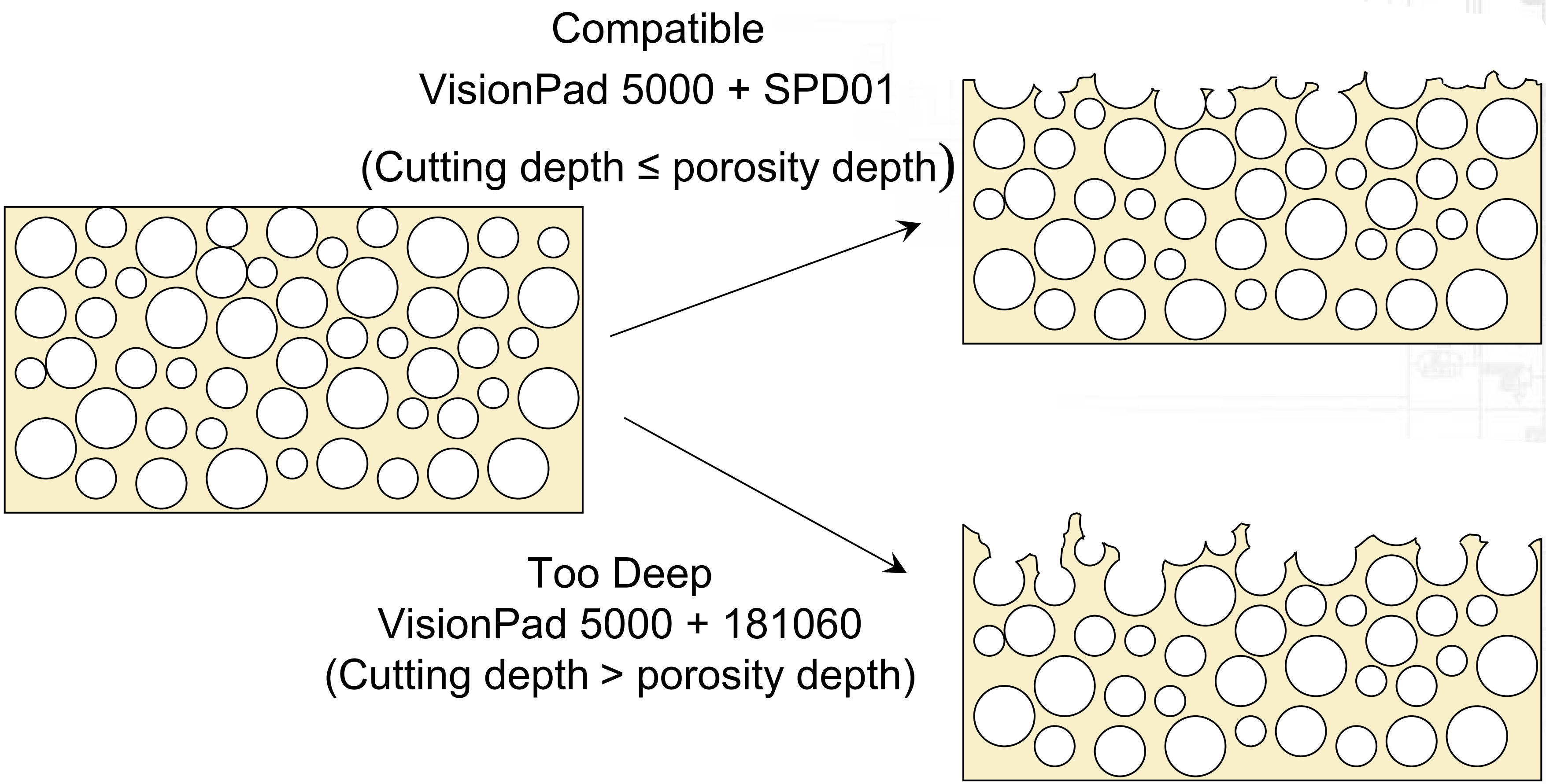


- Final pad surface is the product of the inherent pad texture (porosity) and the conditioner cutting characteristic (near surface roughness)
  - Each pad-conditioner combination will have a **unique (intrinsic) surface structure**
  - Cut rate, cutting characteristics and the resulting near surface roughness can be driven over a large range through conditioner design



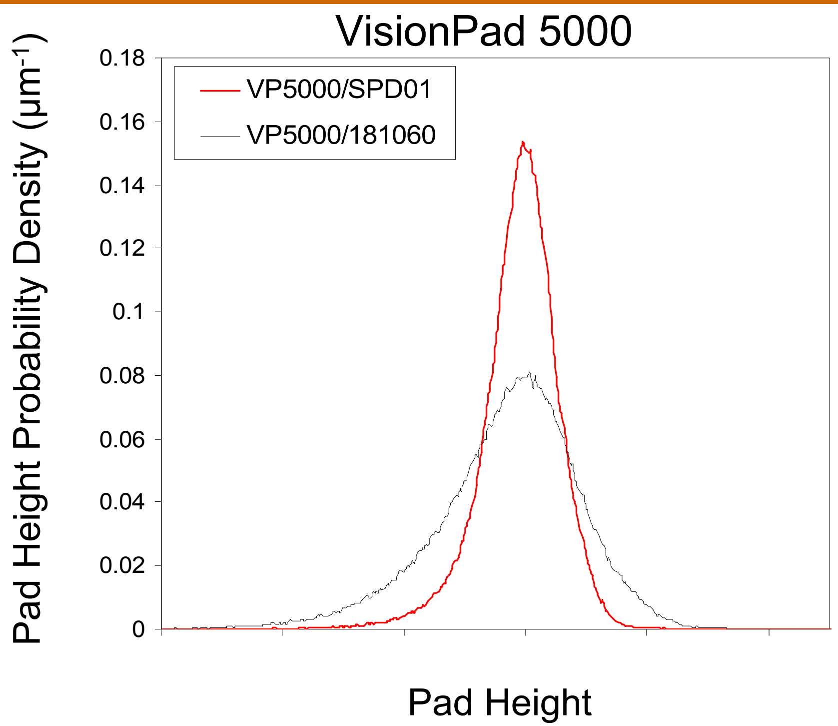
Manipulating the size, shape and density of diamonds can change cutting characteristics and cut rate > 10x

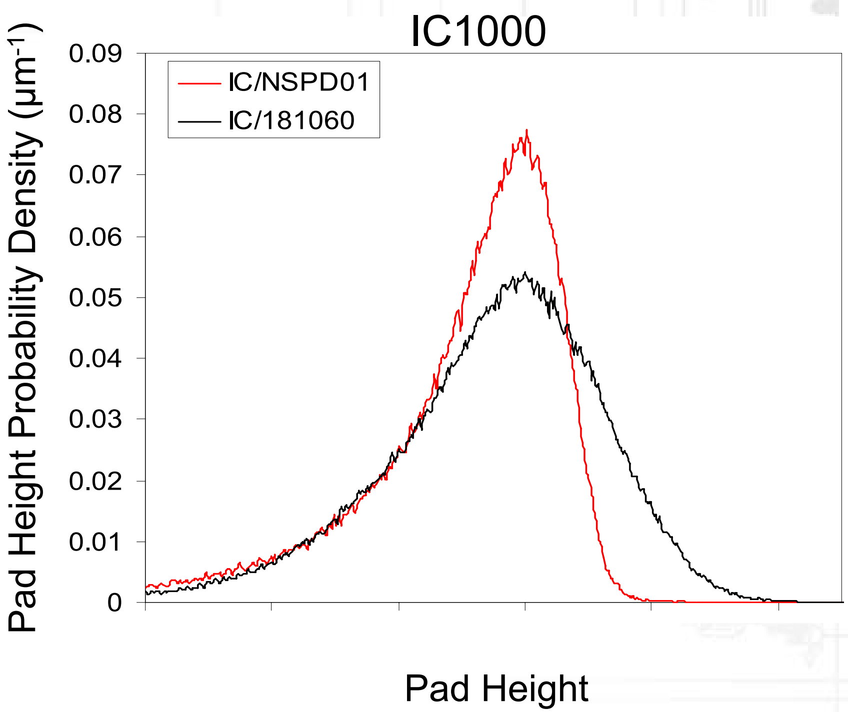
Conditioning for Textural Compatibility



- Materials with different pore structures require conditioning tailored to their specific porosity
- Incompatible conditioning results in a disruption of the natural porosity of the material

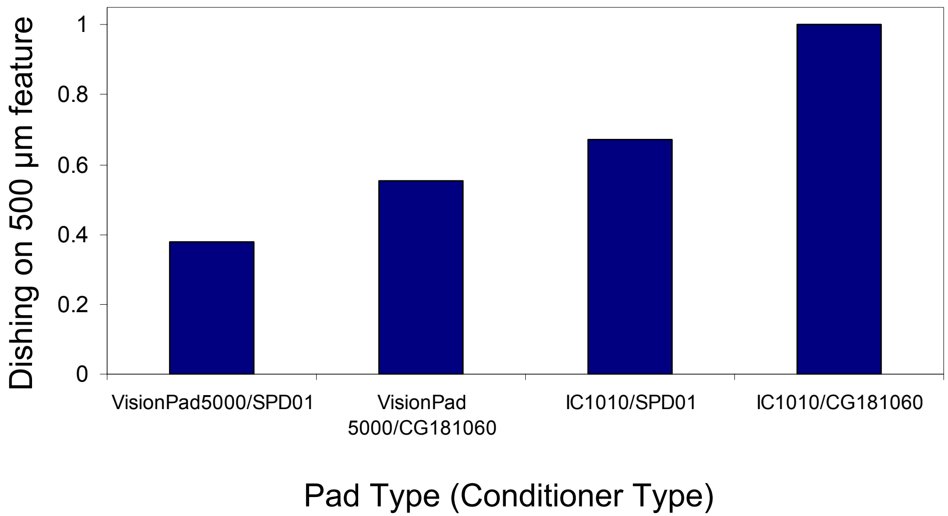
Example: IC1000, VisionPad 5000, NSPD01 & 181060

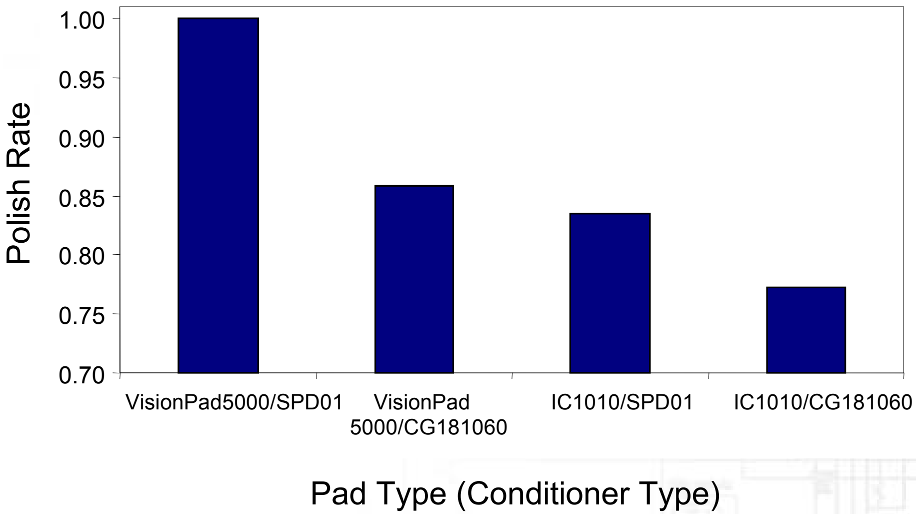




- The natural porosity of IC1000 is compatible with both 181060 and SPD01
  - Note that the negative tail of the distribution is unaffected by conditioning indicating that the natural porosity is intact in both cases
- The natural porosity of VisionPad 5000 is incompatible with 181060 and compatible with SPD01
  - Note that the combination of VisionPad 5000 & 181060 results in a widening of the negative tail of the distribution indicating that the natural porosity of the material has been disrupted

Performance Comparison





- Data from STI Polishing with Celexis™ CX97S slurry
- Dishing and polish rate are significantly improved with the VisionPad 5000/SPD01 combination

Conclusions

- Rohm and Haas Electronic Materials has a comprehensive CMP fundamental research program in place
- This research program is designed to provide rational guidance for product and process design
- Some highlights reviewed here include:
  - Fundamental aspects of pad-wafer contact mechanics
  - Process interactions
  - Next generation pad design