Pad Surface Micro-Topography and Process Temperature Considerations in Planarization

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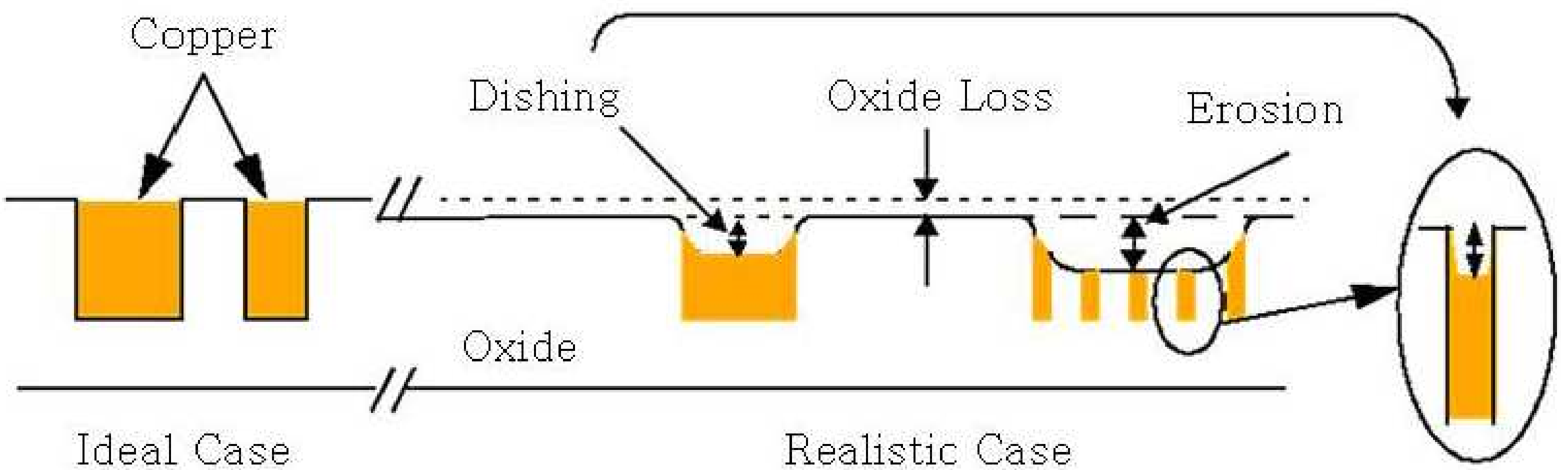
Part 1

Planarization and Pad Surface Micro-Topography

Objectives

- **Gain a deeper understanding and control of factors that affect pad topography and pad-wafer contact area**

- **Prove that pad topography and pad-wafer contact area can predict planarization behavior (on 300 mm blanket and patterned wafers) in terms of removal rate, 'time-to-clear', dishing and erosion.**



<u>Impact</u>

- **If we can prove that pad topography contact area can predict planarization behavior, then IC makers can screen myriad of new (or alternative) consumables analytically instead of resorting to high-cost (therefore high EHS foot-print) blanket and patterned wafer processing.**

- **Shorter 'time-to-clear' means <u>higher module productivity</u> and <u>proportionately less water, slurry, disc and pad consumption.</u>**

- **Less dishing and erosion means <u>higher device yields, and higher module productivity</u> and <u>less consumables use.</u>**

Experimental and Theoretical Approach

- **Polish 300 mm blanket and patterned wafers using a variety of conditions and consumables expected to improve or degrade planarization efficiency (i.e. diamonds with different shapes sizes) ***

- **Examine pad samples under CMP-relevant pressures and analyze surface contact area and topography via confocal microscopy.**

- **Correlate planarization behavior (RR, time-to-clear, dishing and erosion) with contact area and topography data.**

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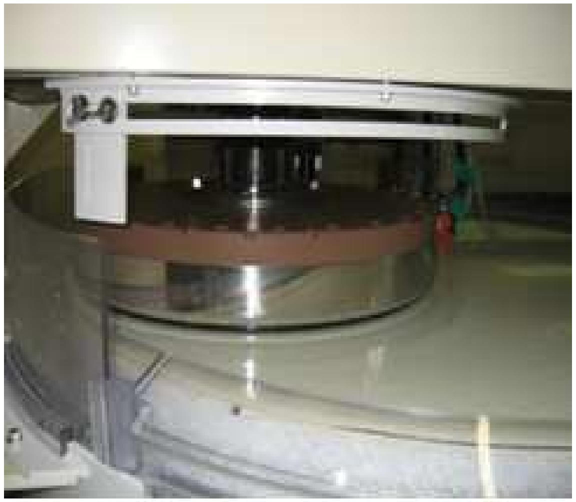
Note: The goal IS NOT to select and recommend (depending on the polishing outcome) a particular consumables supplier over another. Rather, the products in this study have been chosen to simply provide the widest range of polishing outcomes in an attempt to scientifically explain the observations.

APD – 800 300 mm Polisher and Tribometer



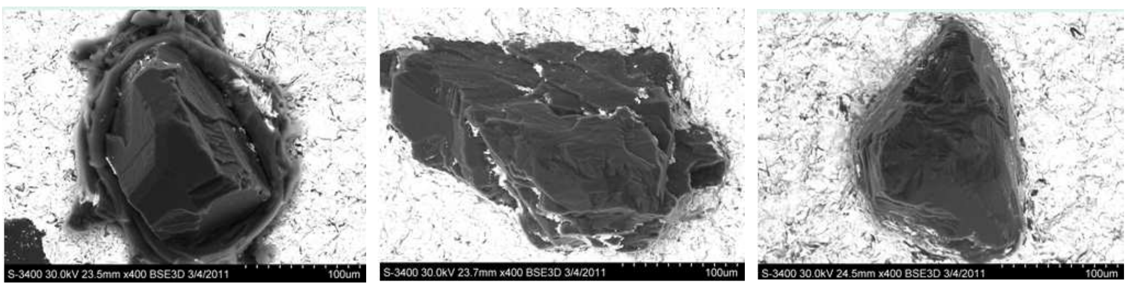
Polishing Conditions

- **Pressure: 1.7 PSI**
- **Sliding velocity: 1.0 m/s**
- **Polishing time (blanket wafers): 1 minute**
- **Slurry: CMC iQ600-Y75 with 30 percent H_2O_2 at 300 cc per minute**
- **Conditioning: In-Situ at a down-force of 6 lb_f**

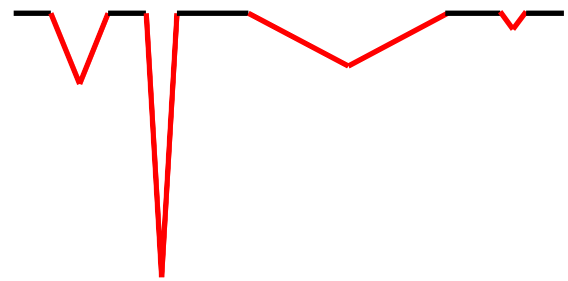
Diamond Discs Tested

Example of 3M's Aggressive Diamonds –

Smaller and 'irregular'

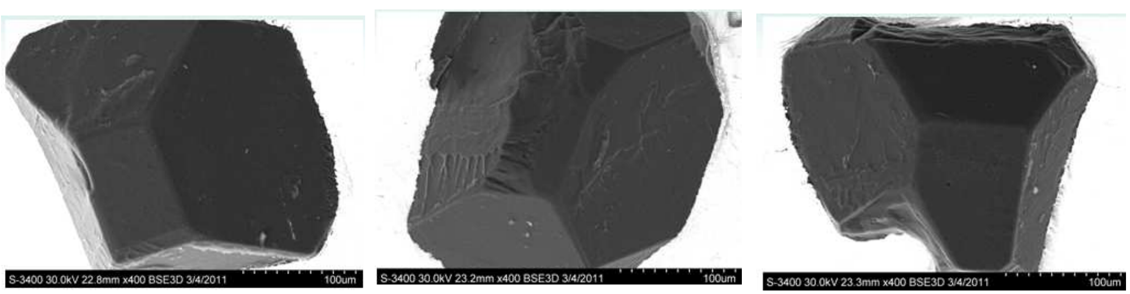


Furrows cut on the pad surface by active diamonds



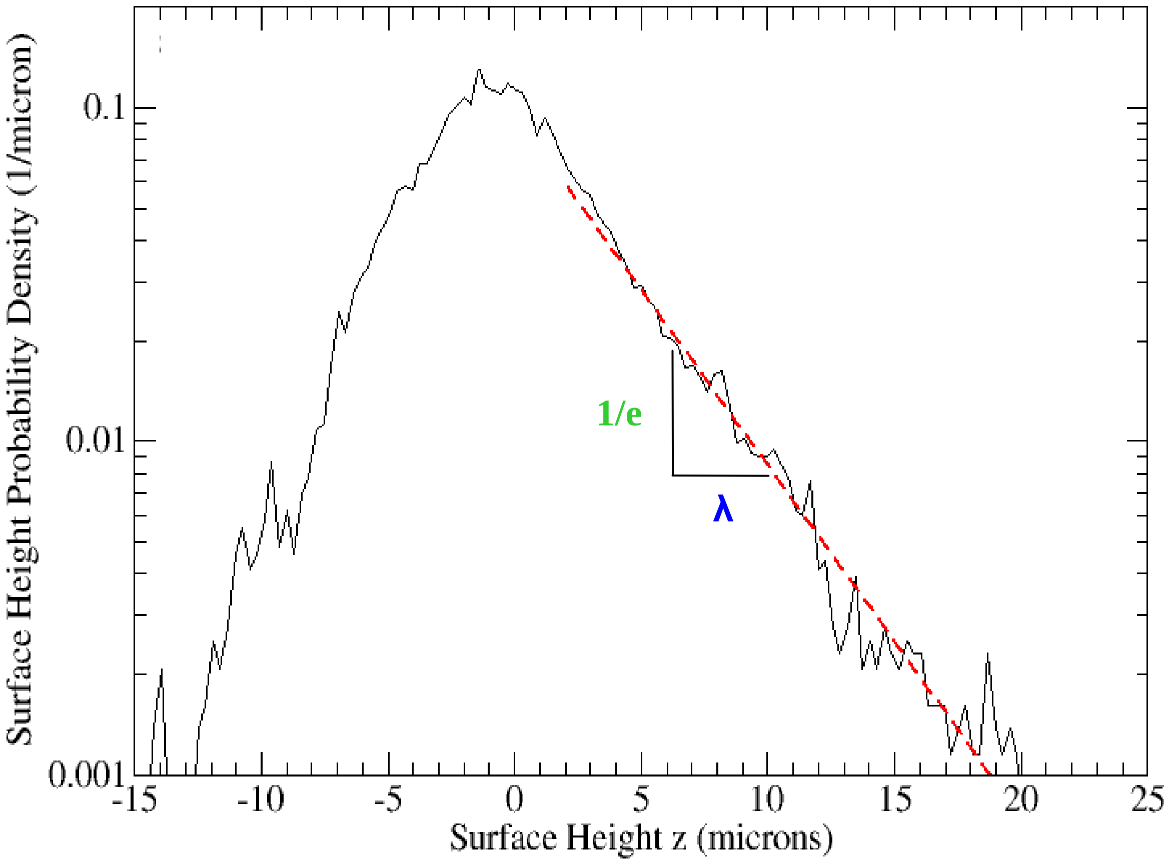
Example of Ehwa's Aggressive Diamonds –

Larger and 'blocky'



Disc	Total Surface Furrow Area (micron^2)
3M	3,996
Ehwa	4,526

Pad Surface Abruptness (Lambda) Extracted from Confocal Microscopy Topographic Data



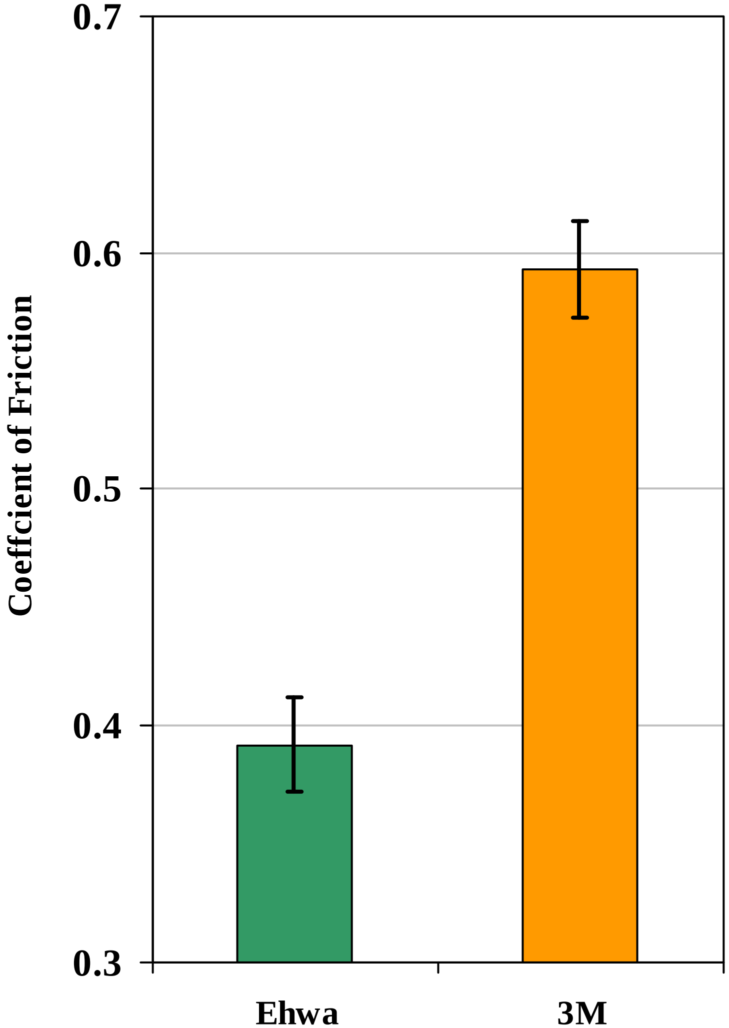
When the asperity summits have exponentially distributed heights, then the right hand tail of the probability density function will be linear on a log scale.

The pad abruptness factor (λ) is a <u>decay length</u> (the distance over which the tail drops by a factor of *e*).

A pad with larger λ means a rougher pad contacting surface.

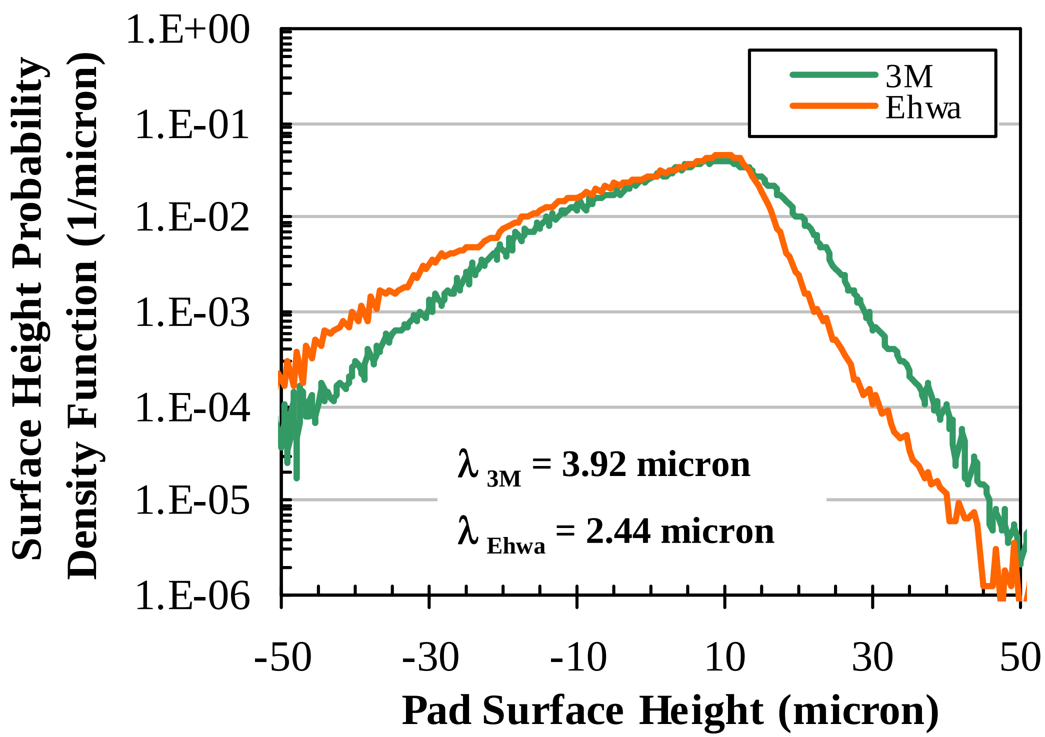
Coefficient of Friction

Blanket Wafer Polishing



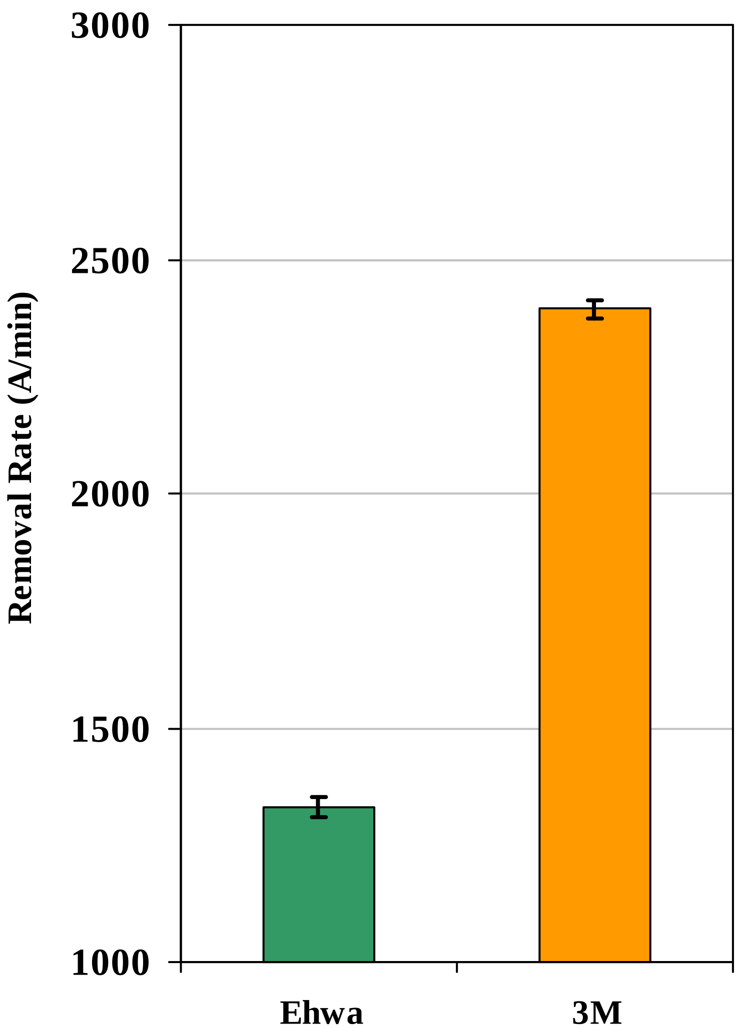
COF for 3M > COF for Ehwa.

This is due to the fact that λ (surface abruptness) for 3M is greater than Ehwa.



Copper Removal Rate

Blanket Wafer Polishing



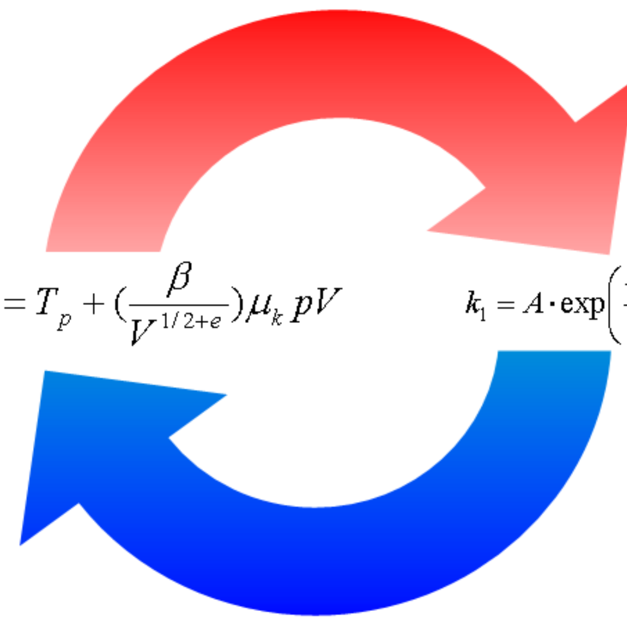
RR for 3M > RR for Ehwa.

Consistent with the Langmuir-Hinshelwood mechanism for copper polish (used with great success over the past 6 years).

$$\underline{Cu} + nR \xrightarrow{k_1} \underline{L}$$

$$\underline{L} \xrightarrow{k_2} L$$

$$RR = \frac{M_w}{\rho} \frac{k_1 C}{1 + \frac{k_1 C}{k_2}}$$



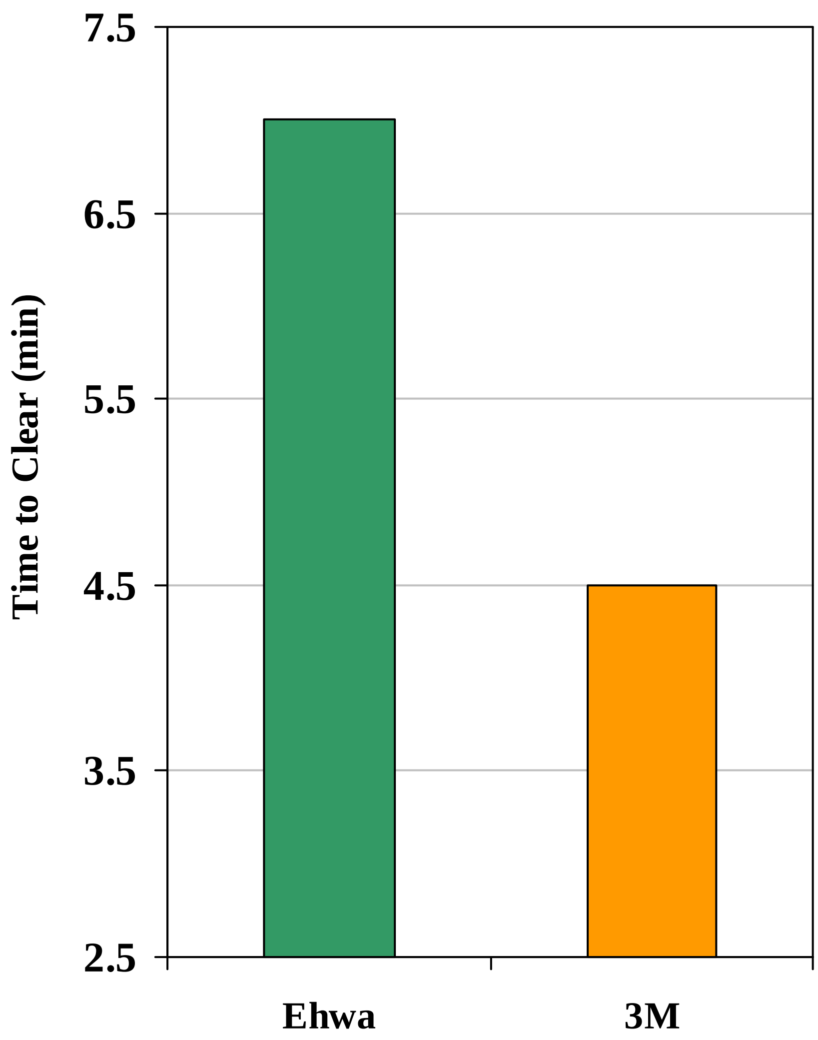
$$T = T_p + \left(\frac{\beta}{V^{1/2+e}}\right)\mu_k pV$$

$$k_1 = A \cdot \exp\left(\frac{-E}{kT}\right)$$

$$k_2 = c_p \mu_k pV$$

Polishing Time Required for Copper Clearing

Patterned Wafer Polishing



TTC for 3M < TTC for Ehwa.

Consistent with blanket RR data and are supported by an additional fact that for IC1000:

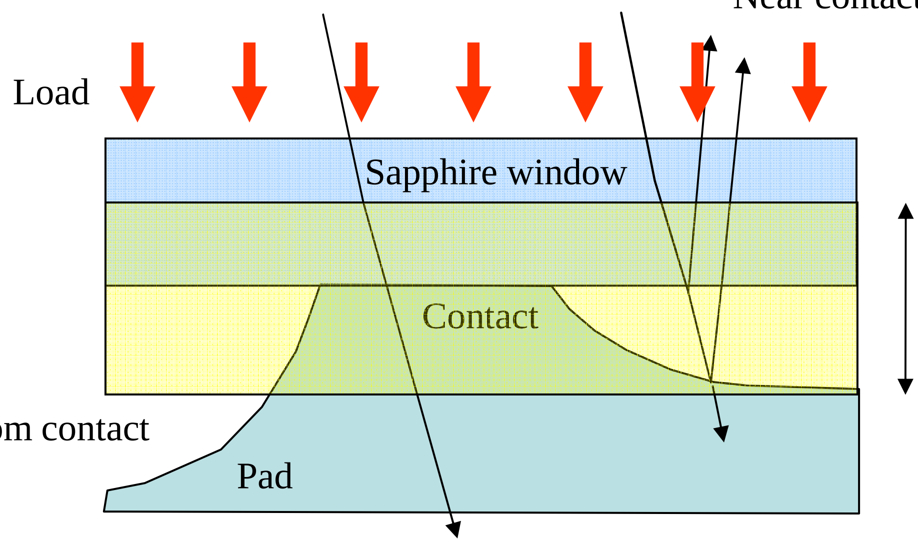
(a) Contact Area (CA) for Ehwa > CA for 3M (therefore localized pad-wafer pressure is greater for 3M than for Ehwa).

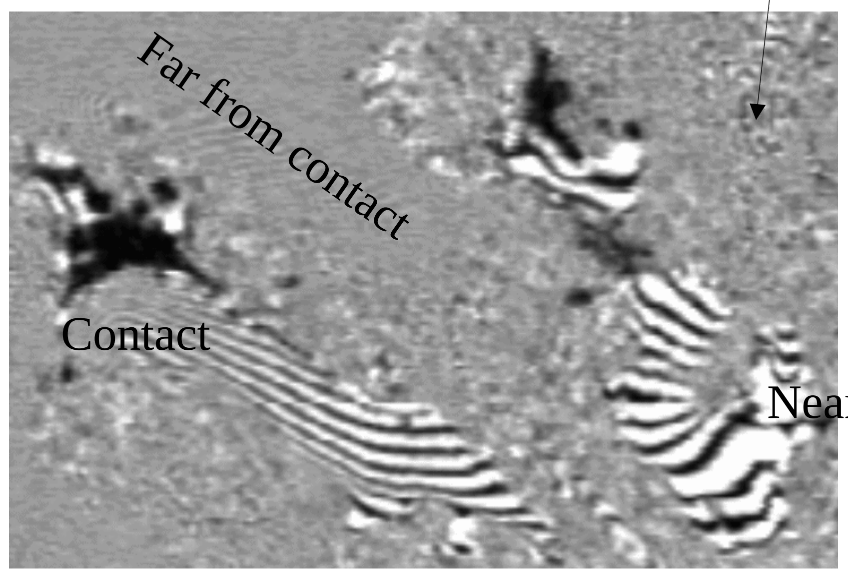
(b) Near Contact Area (NCA) for Ehwa >> NCA for 3M (therefore more fractured and collapsed pore walls which make the pad surface more lubricated resulting in lower COF and RR for Ehwa). NCA is represented by large 'zebra patterns' (next slide).

Laser Confocal Microscope

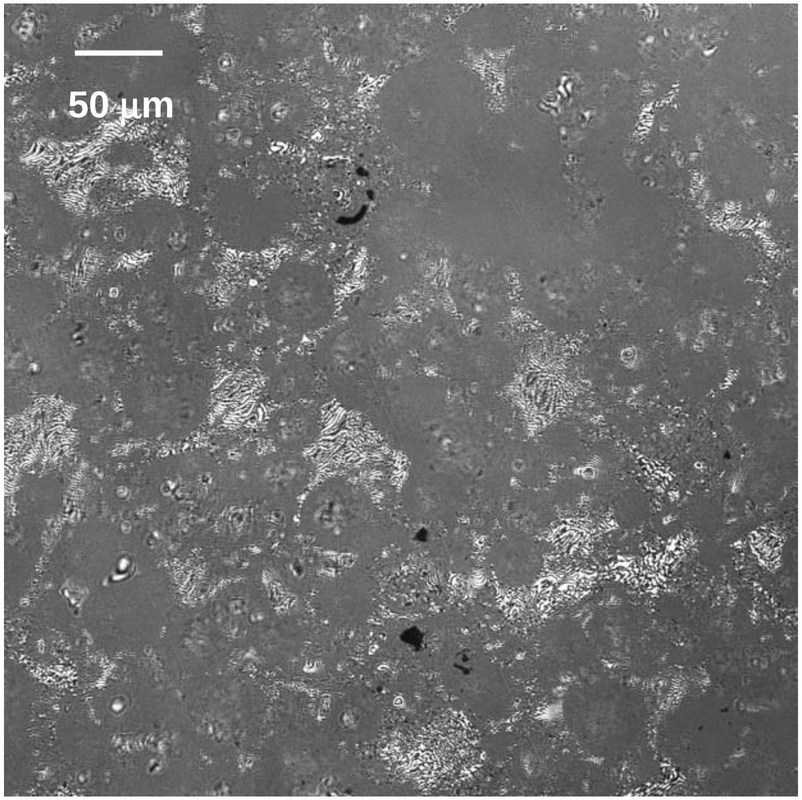
Pad surface contact area analysis was performed using a Zeiss LSM 10 Meta NLO laser confocal microscope.

Confocal Contact Area Measurements

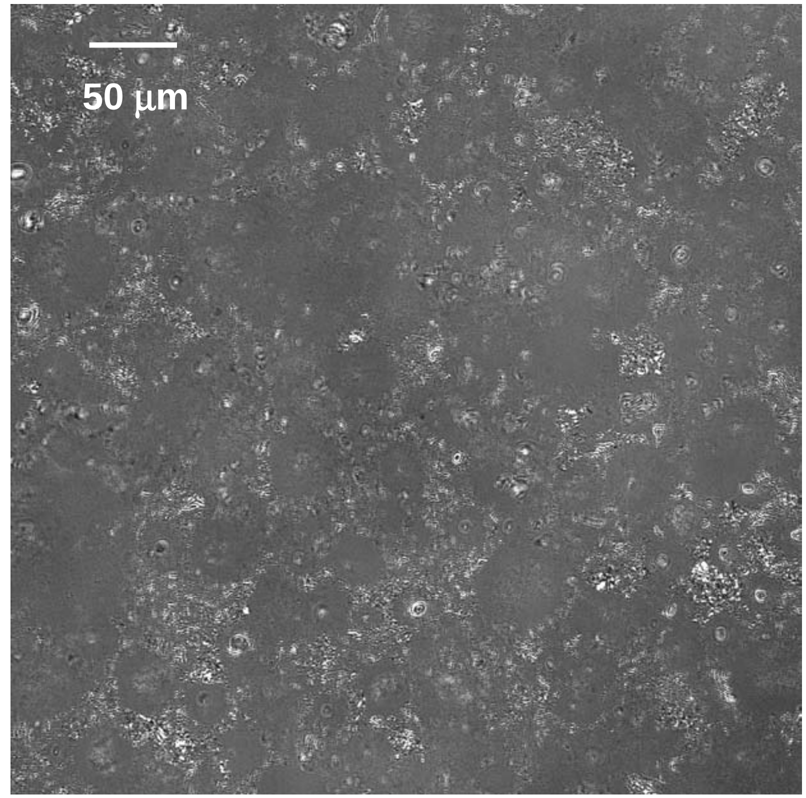




Contact Area (CA) and Near Contact Area (NCA)



Ehwa CA = 0.044 percent

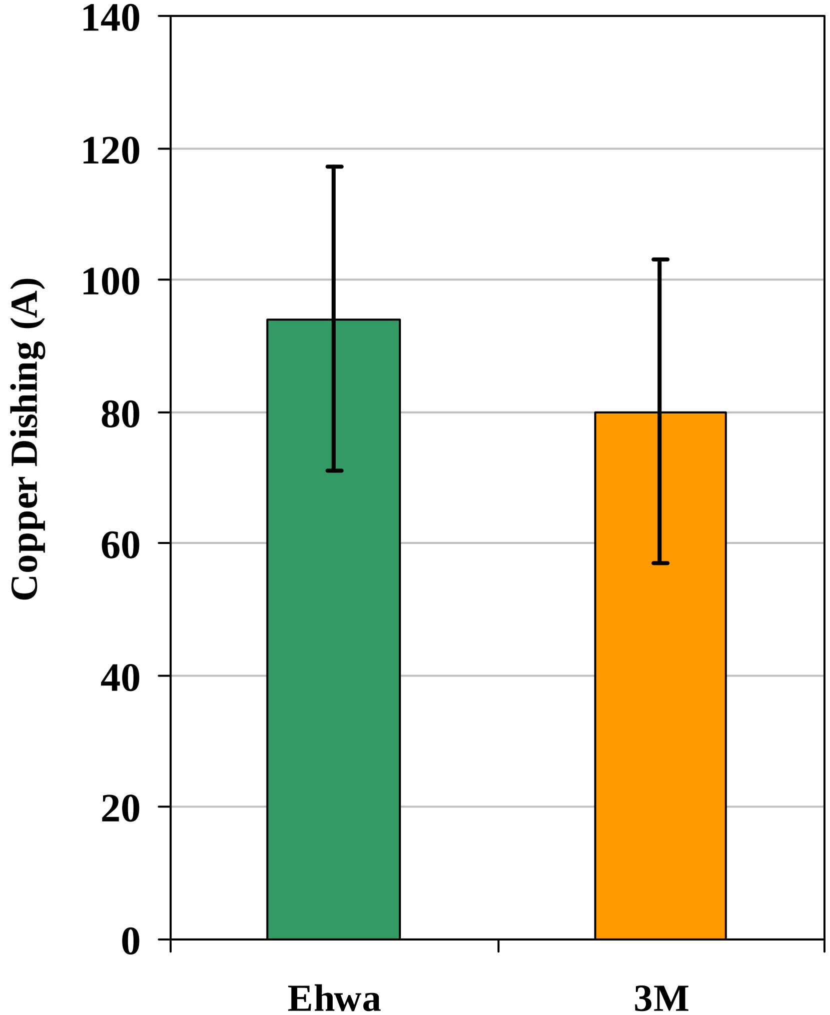


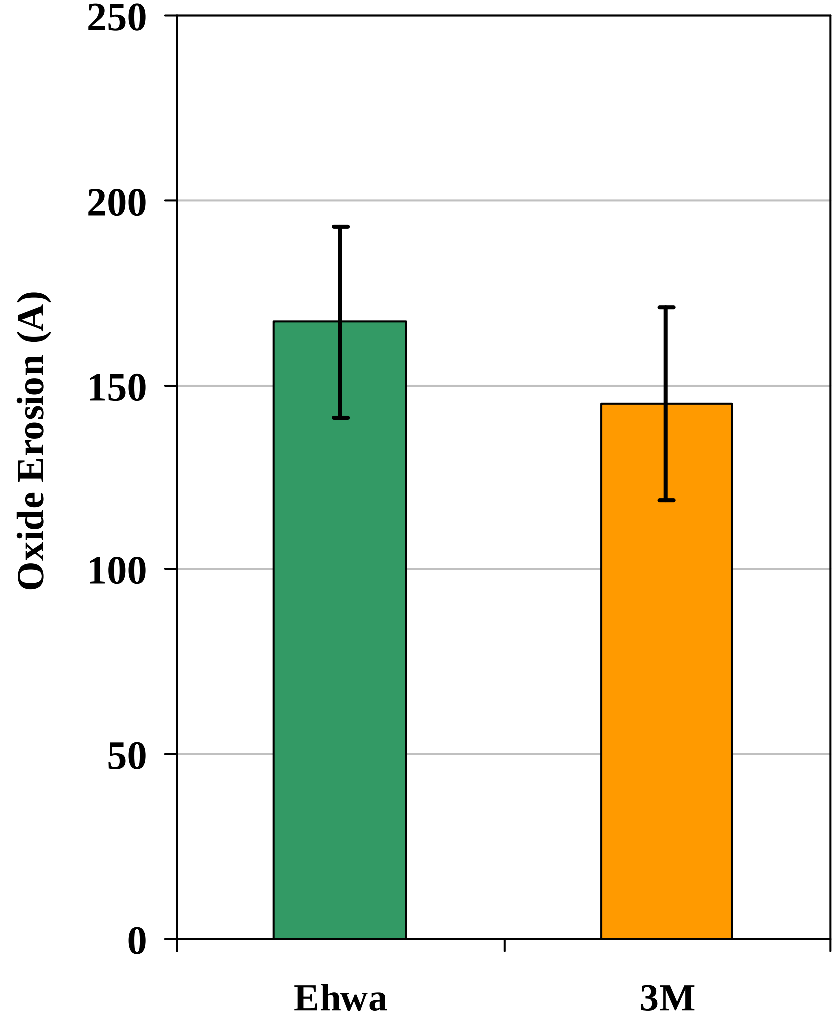
3M CA = 0.001 percent

Lower contact area → Higher contact pressure → Higher removal rate → Shorter time-to-clear

Dishing (left) and Erosion (right) Comparison

Patterned Wafer Polishing



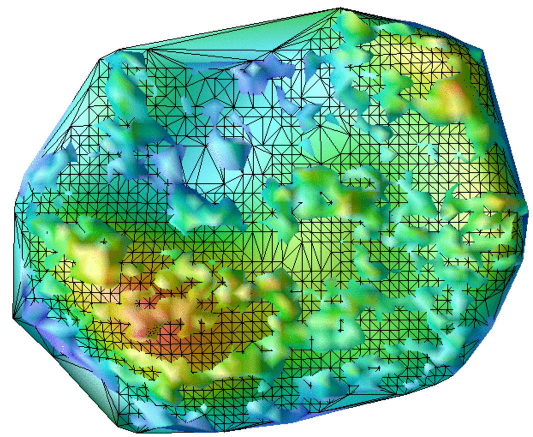


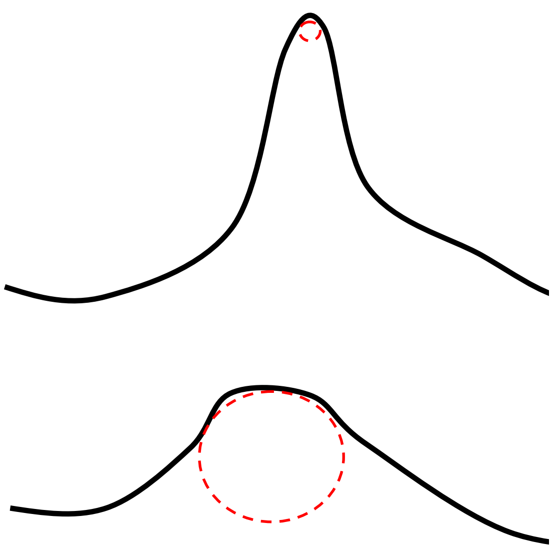
Pad Summit Curvature from Pad Topography Data

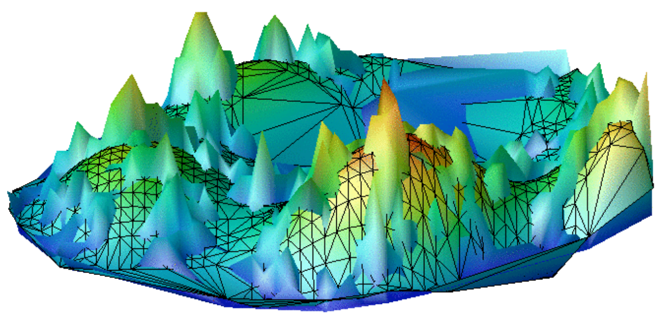
The radius of curvature (R) at the maximum of a curve is the radius of the best fitting circle at that point.

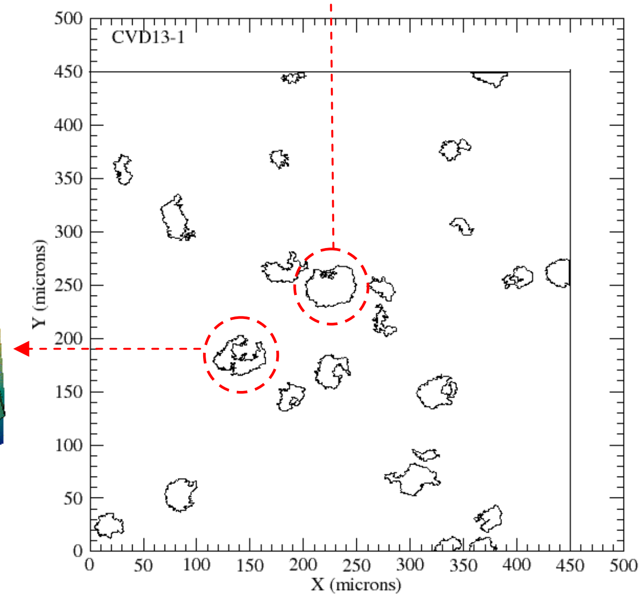
The curvature (K) is the reciprocal of the radius of curvature.

K = 1/R, so the smaller the radius, the greater the curvature (see below).

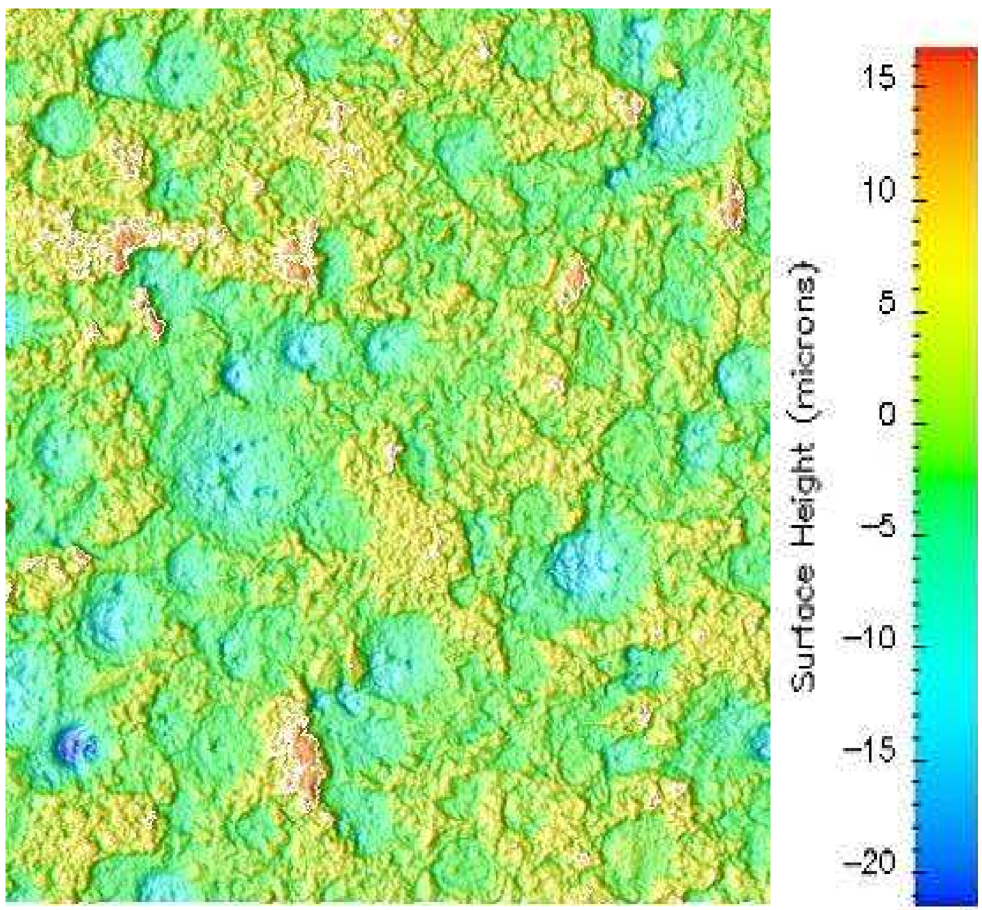








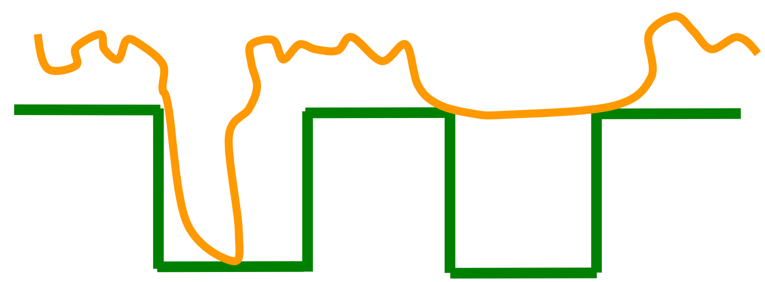
Dishing and Erosion vs. Summit Curvature



The Ehwa conditioner generated sharper summits (asperities) than the 3M conditioner.

The probability of sharper asperities penetrating and polishing the ‘down’ features of a patterned wafer is greater, therefore the Ehwa conditioner resulted in higher dishing and erosion.

Disc	K_s (micron^{-1})
3M	1.85
Ehwa	3.62



Summary

- **For blanket copper wafer polishing, Ehwa resulted in 45 percent lower COF and 35 percent lower blanket RR than 3M.**

- **Consequently, 3M resulted in 35 percent shorter time-to-clear than Ehwa.**

- **3M also resulted in less dishing and erosion (both by 15 percent) compared to Ehwa.**

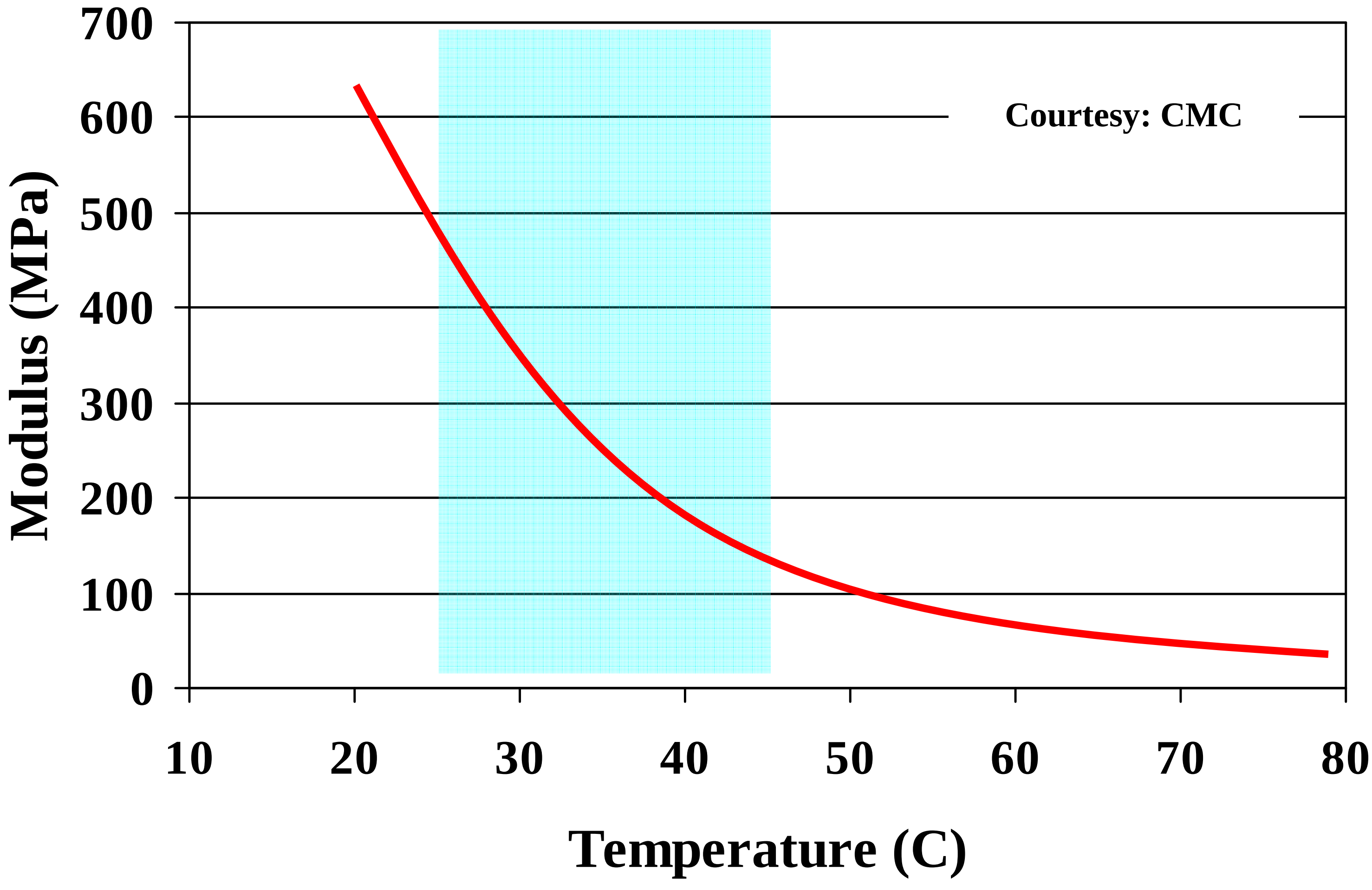
- **The smaller pad surface contact area and higher surface abruptness generated by the 3M disc were the reasons for the higher RR.**

- **Sharper asperities generated by Ehwa disc contributed to the observed higher dishing and erosion.**

Part 2

Process Temperature and Pad Surface Micro-Topography

D100 Bulk Modulus vs. Temperature



Background and Objective

Background

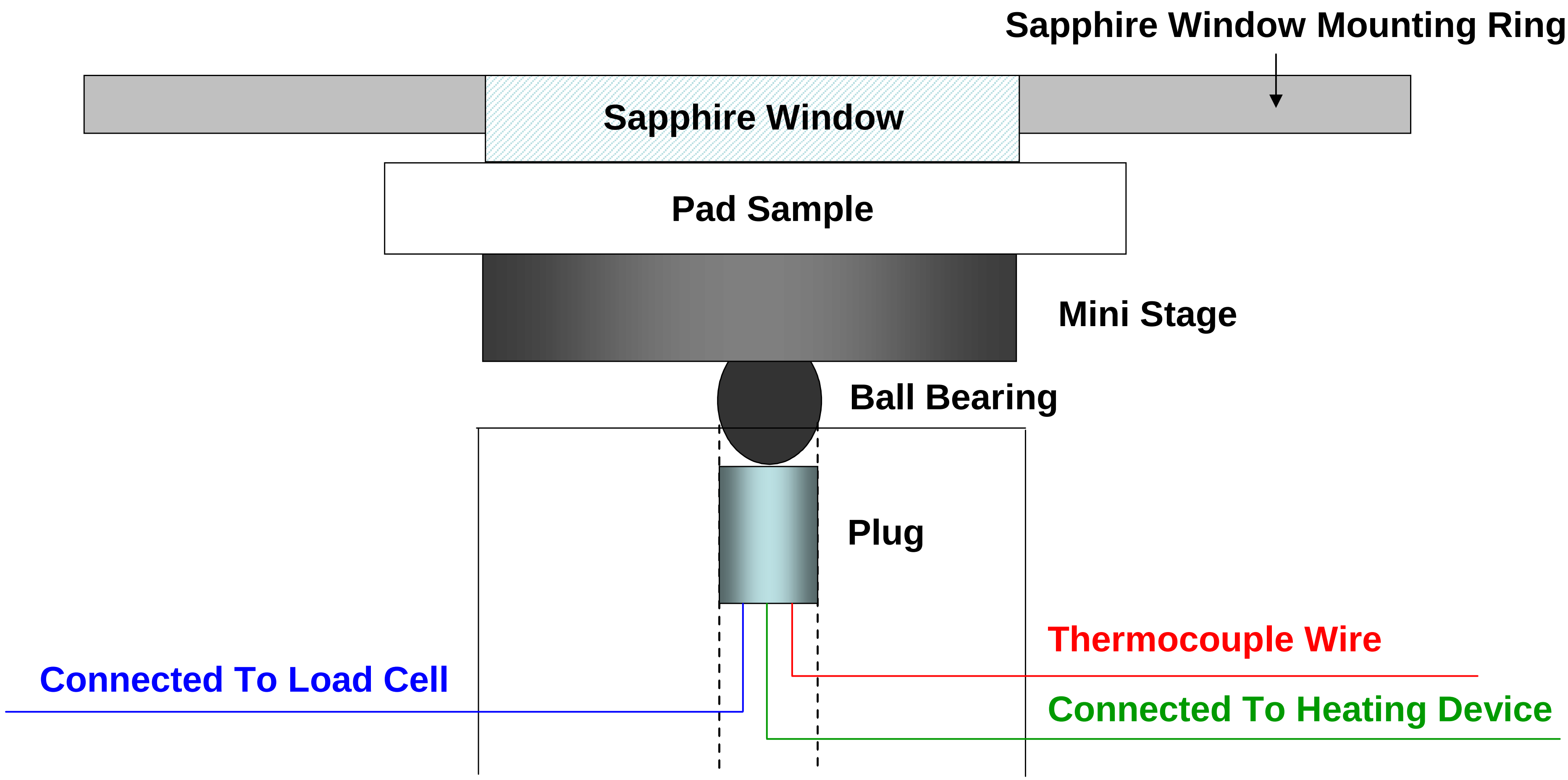
- Characterization of pad-wafer contacts provides crucial information for gaining insight into the mechanical interactions between pad asperities and wafer surface and obtaining fundamental understanding of the mechanism of CMP.

- During 300-mm copper and tungsten CMP processes used in the current state-of-the-art IC manufacturing factories, the pad surface temperature can exceed 50 ºC.

Objective

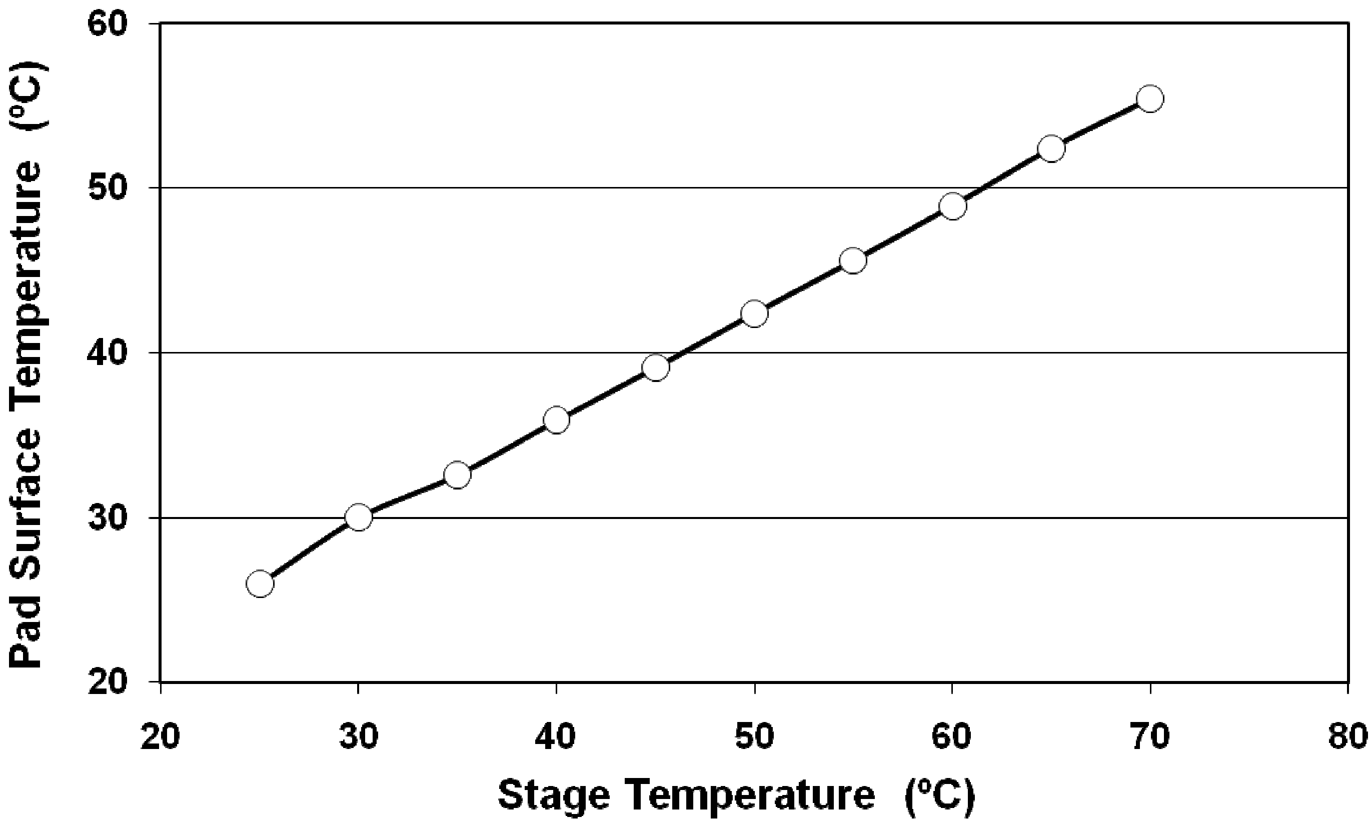
- Investigate the effect of temperature on pad surface contact area.

Heated Pad Sample Holder Assembly



A heating device was attached to the sample holder to heat the stage and pad sample during contact area measurement.

Pad Surface Temperature Calibration

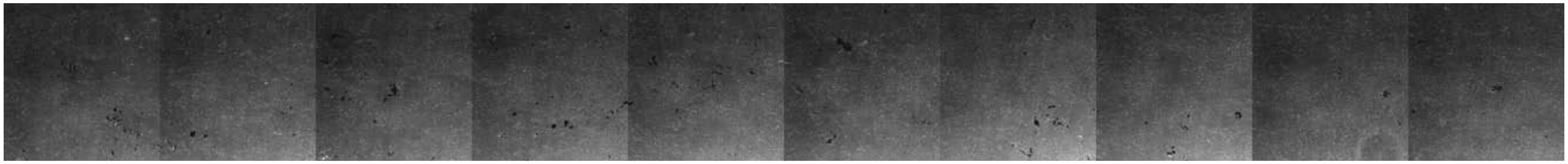


Prior to pad surface contact area measurement, a calibration test was performed to establish the correlation between the pad surface temperature and mini stage temperature.

During pad surface contact area measurement, the mini stage temperature was controlled to achieve the desired pad surface temperature.

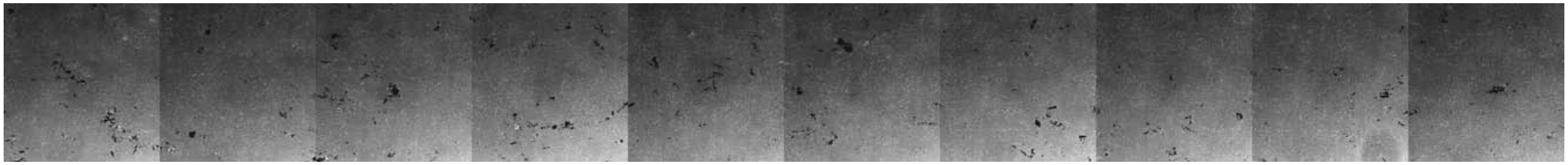
Pad Surface Contact Images at 4 PSI

25℃



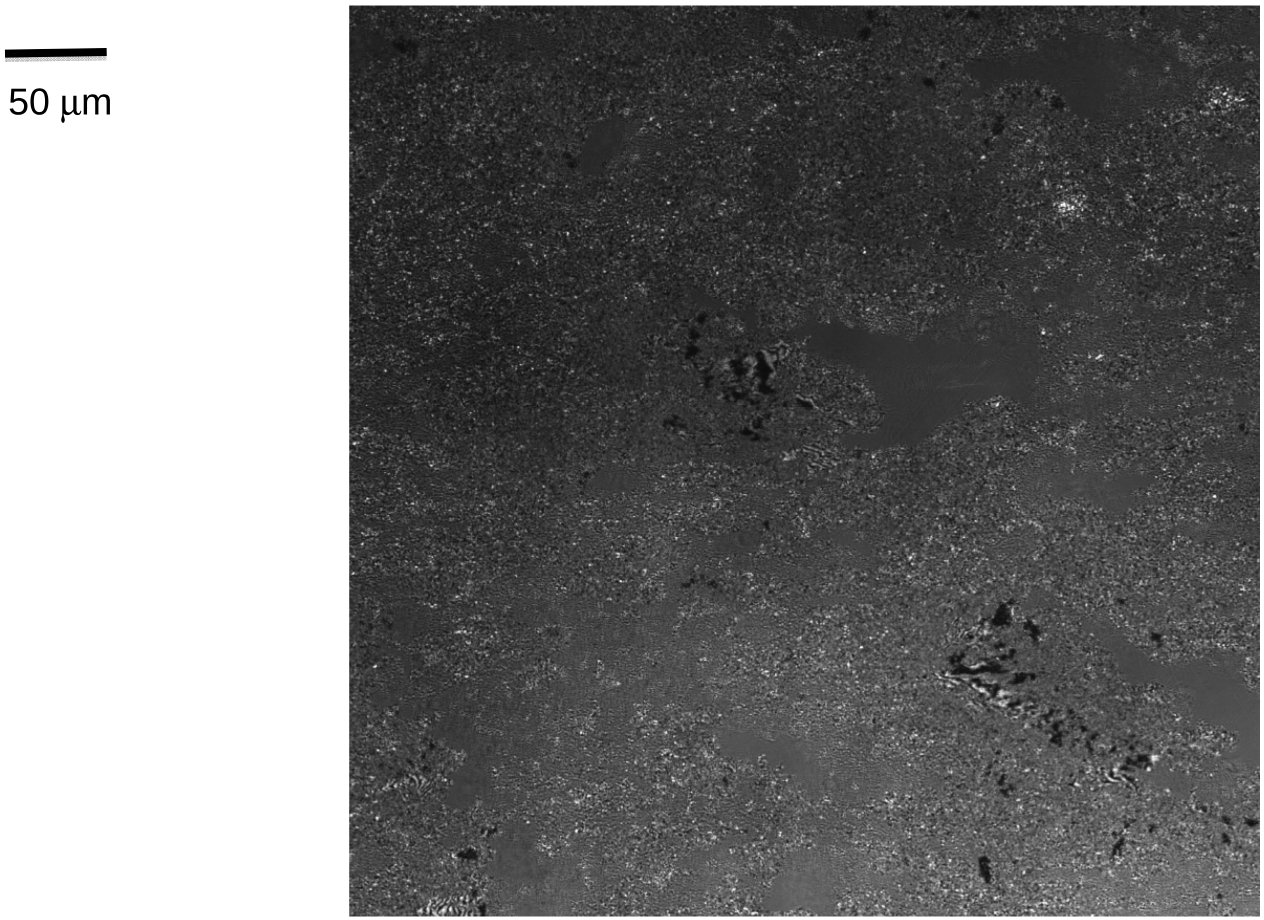
35℃

45℃



Pad surface contact images were taken on a selected land area (4.5 x 0.45 mm^2) of a CMC D100 pad sample at pad surface temperatures of 25, 35, and 45 ºC.

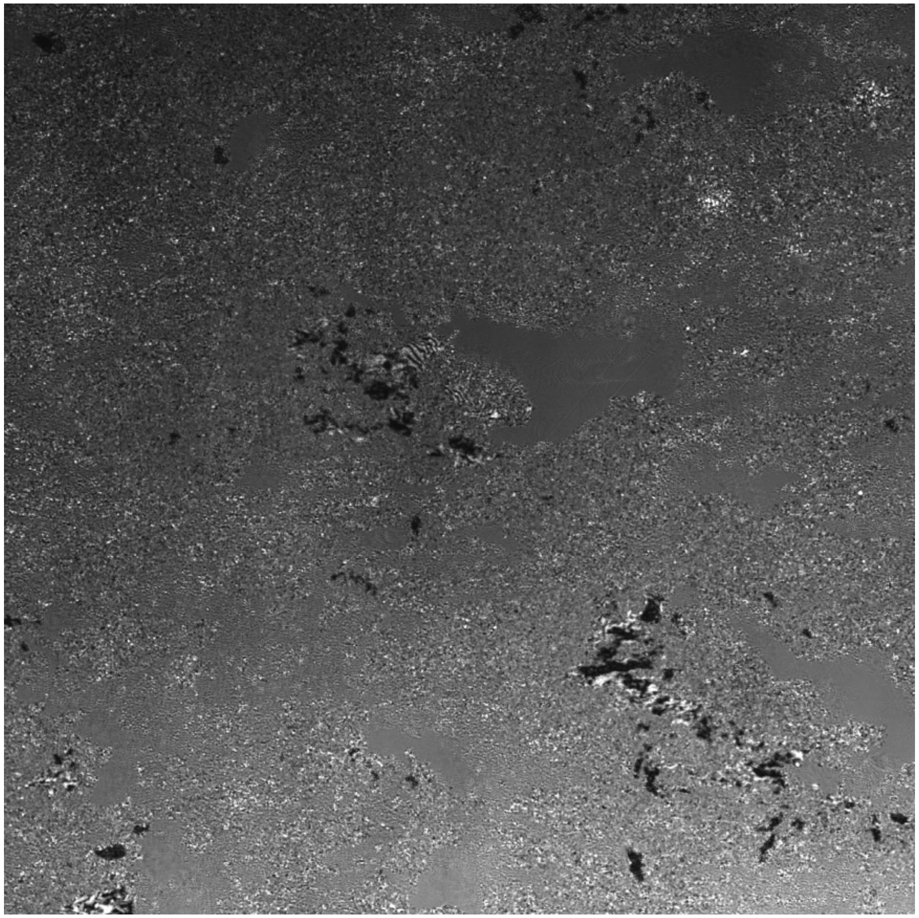
Example: Pad Surface Contact Image at 25 ºC



Contact area percentage = 0.044%

Example: Pad Surface Contact Image at 35 ºC

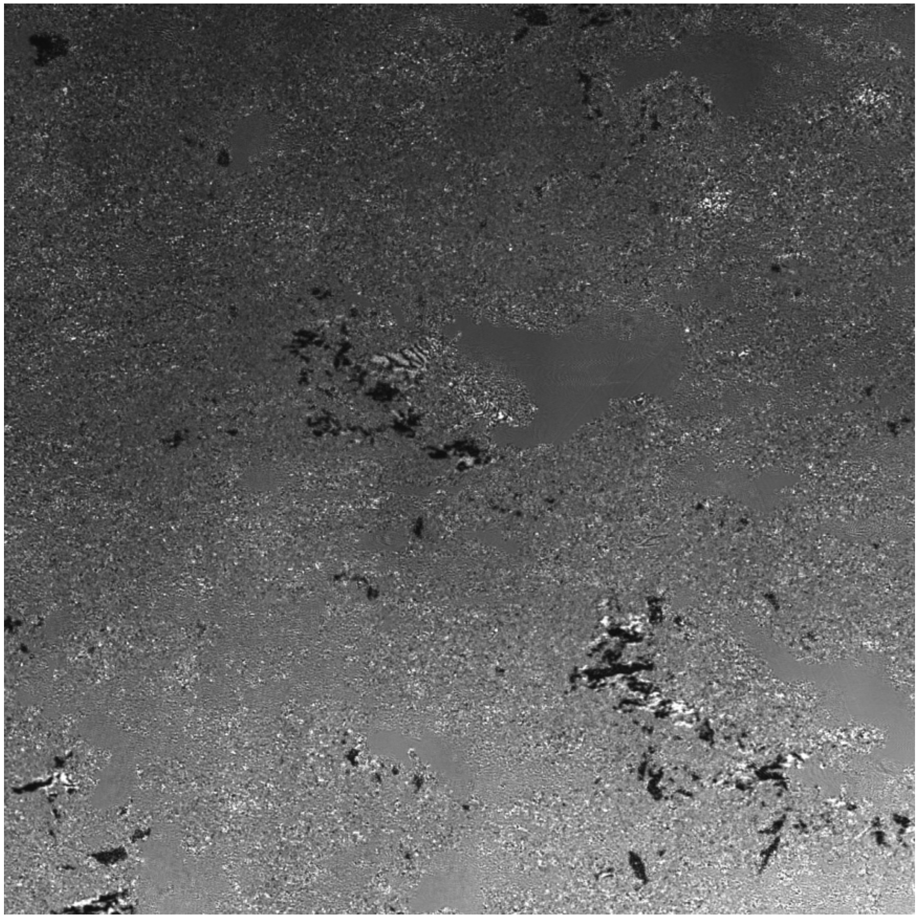
50 μm



Contact area percentage = 0.083%

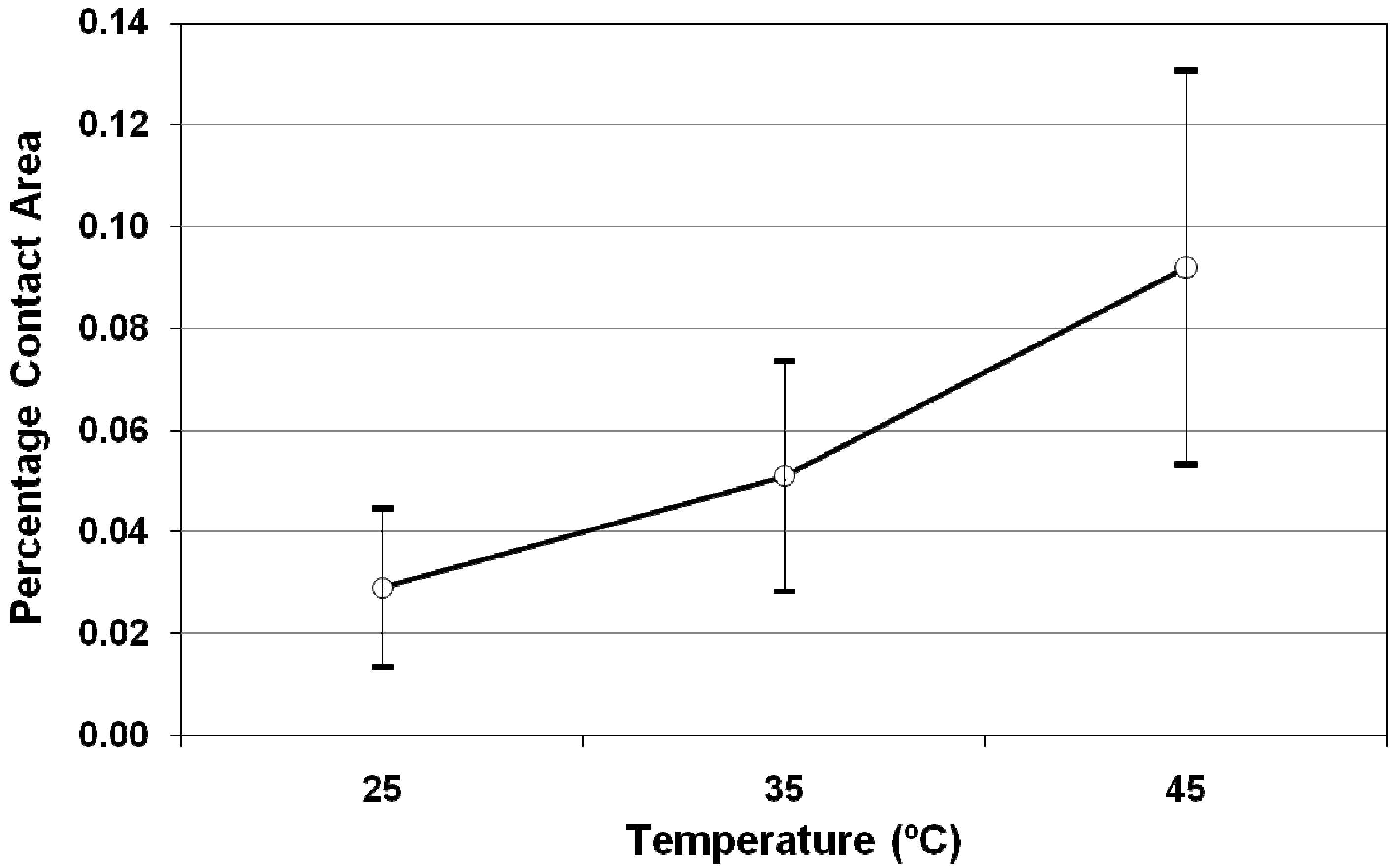
Example: Pad Surface Contact Image at 45 ºC

50 µm



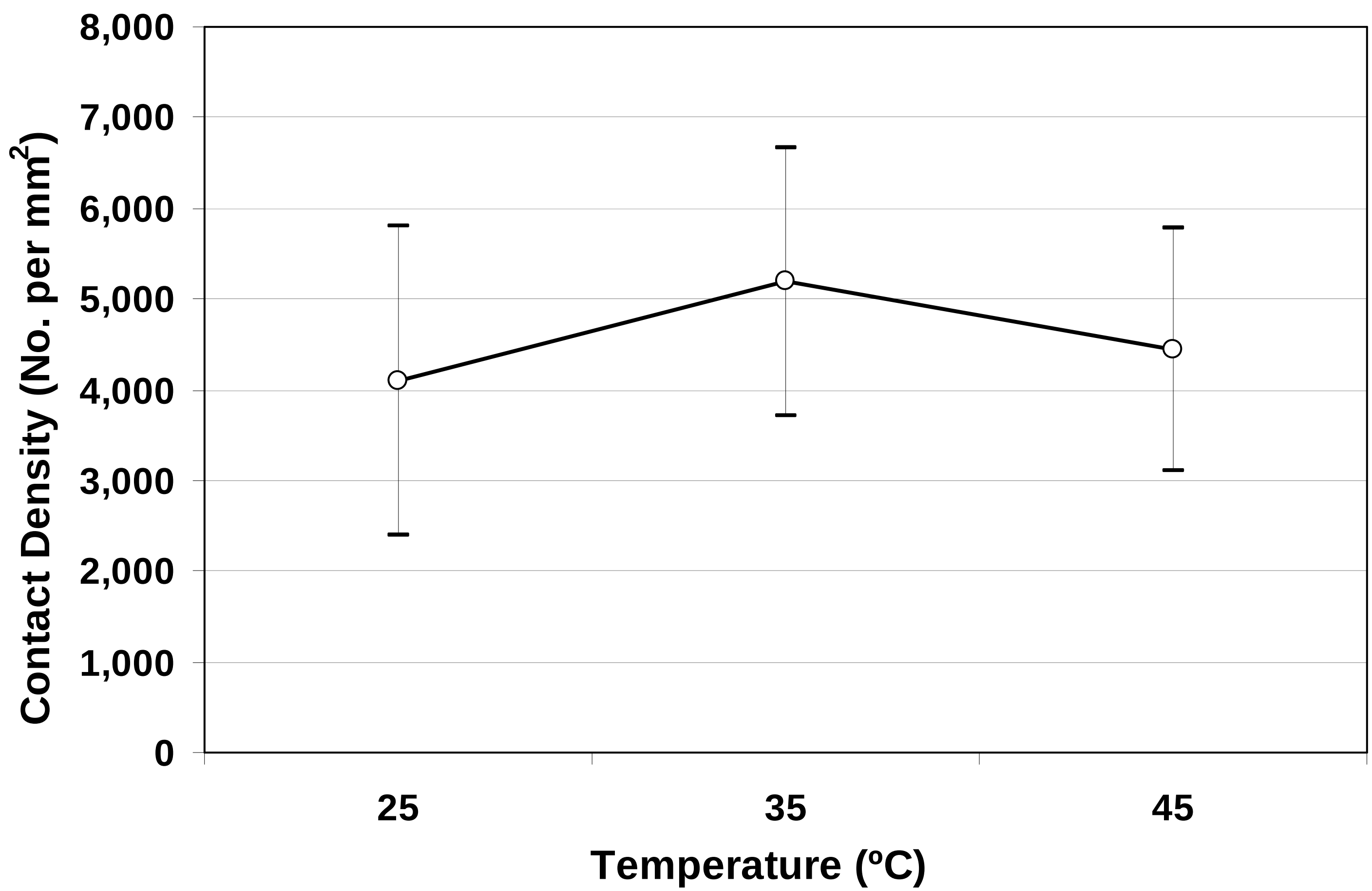
Contact area percentage = 0.164%

Contact Area Percentage Comparison



When pad surface temperature increased from 25 to 35 ºC, average contact area percentage increased from 0.029% to 0.051%, and it increased further to 0.092% when the pad surface temperature increased from 35 to 45 ºC.

Contact Density Comparison



The contact density remained basically unchanged at different pad surface temperatures.

Summary

A custom-made sample holder was designed to heat pad samples during confocal microscopy.

The pad surface contact area was successfully measured at different temperatures.

The pad surface contact area increased more than 3X when the pad surface temperature increased from 25 to 45 ºC. On the hand, the contact density did not change significantly at different temperatures.

It is critical to measure pad surface contact area at elevated temperatures that are in the range of the current CMP processes to provide more relevant and accurate pad surface analysis.