# Lowering Slurry Use and Waste in CMP Processes

## Investigation of the Relationship between Planarization and Pad Surface Micro-Topography


**PIs:**

- **Ara Philipossian, Chemical and Environmental Engineering, UA**

**Graduate Students:**

- **Yubo Jiao, Ph. D. candidate, Chem. and Env. Engineering, UA**
- **Xiaoyan Liao, Ph. D. student, Chem. and Env. Engineering, UA**
- **Zhenxing Han, Ph. D. student, Chem. and Env. Engineering, UA**

**Other Researchers:**

- **Yasa Sampurno, Research Associate, Chem. and Env. Engineering, UA**
- **Yun Zhuang, Research Associate, Chem. and Env. Engineering, UA**

# Lowering Slurry Use and Waste in CMP Processes

## Investigation of the Relationship between Planarization and Pad Surface Micro-Topography

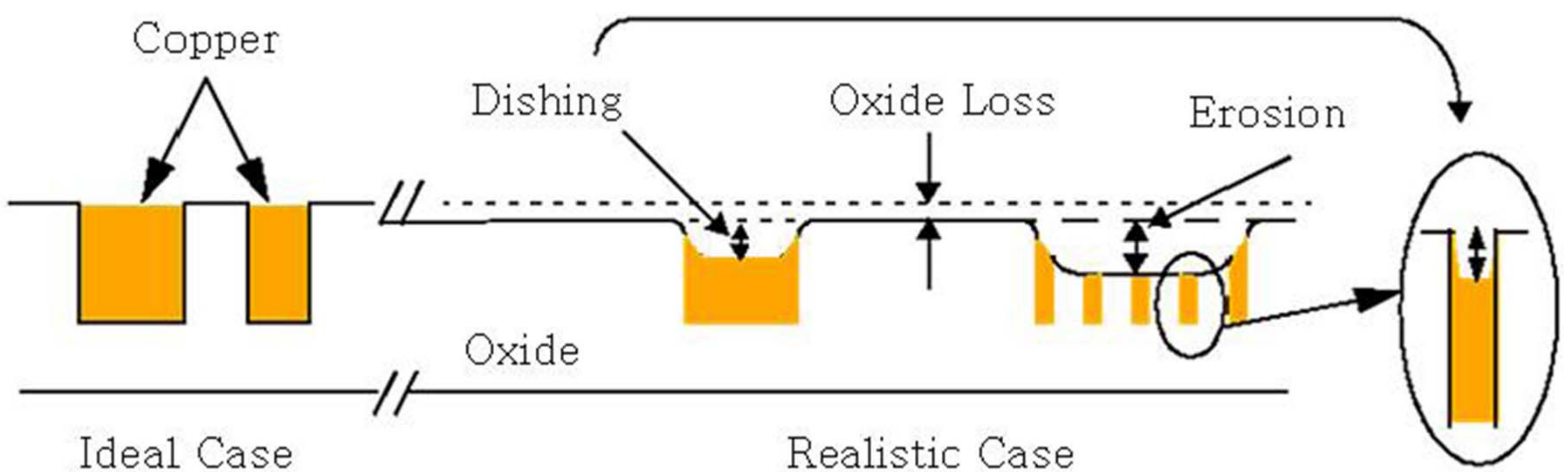
**Cost Share (other than core ERC funding):**

- **In-kind donation (conditioner discs) from Ehwa**
- **In-kind donation (conditioner discs) from 3M**
- **In-kind donation (polishing pads) from Dow Electronic Materials**
- **In-kind donation (polishing pads and slurry) from Cabot Microelectronics**
- **In-kind donation (wafers and dishing and erosion analysis) from Intel**
- **In-kind support (confocal microscopy and image analysis) from Araca**

# 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.



# ESH Metrics and Impact

- **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 higher module productivity and proportionately less water, slurry, disc and pad consumption.**

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

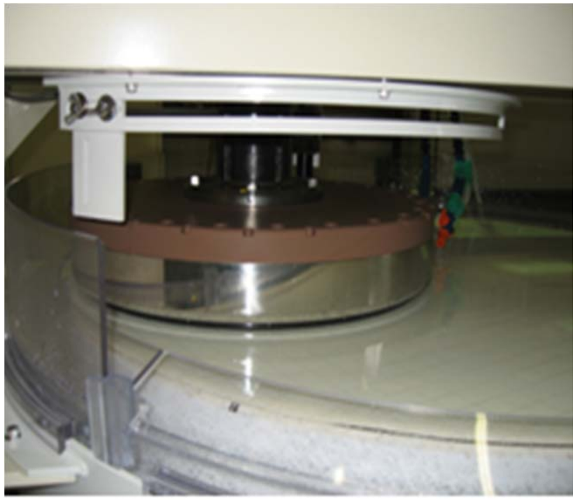
- **Our goal is to realize a 30 percent consumables reduction through pad topography and process contact area tuning.**

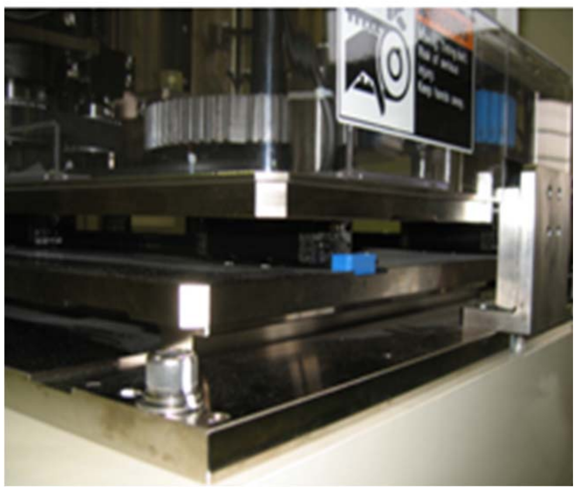
# Experimental and Theoretical Approach

- **Polish 300-mm blanket and patterned wafers using a variety of conditions and consumables * (i.e. pads with different hardness/porosity and diamonds with different levels of aggressiveness) expected to improve or degrade planarization efficiency.**
- **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.**

*** 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

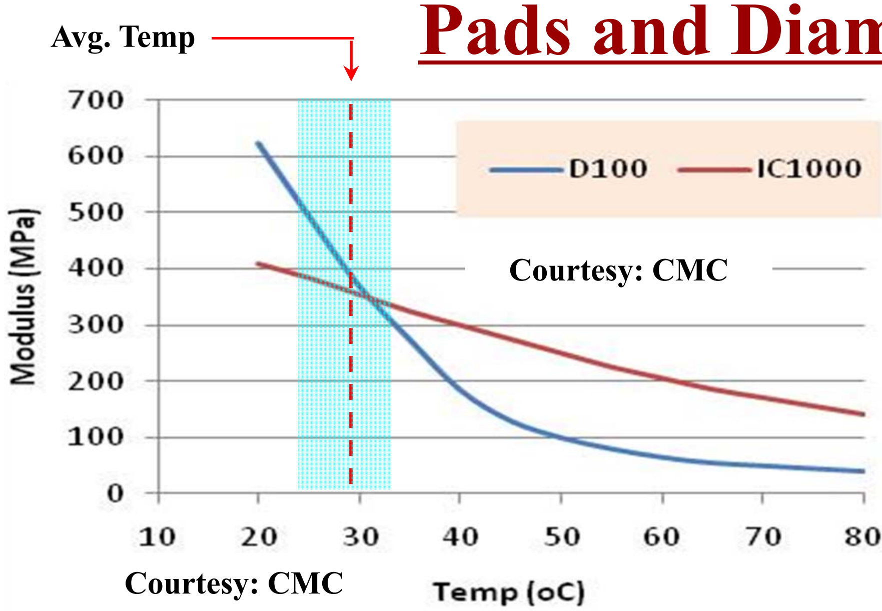


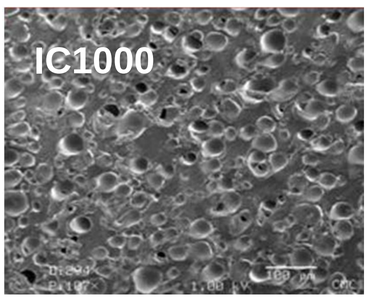


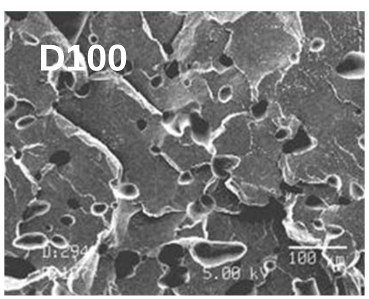
**Polishing Conditions**

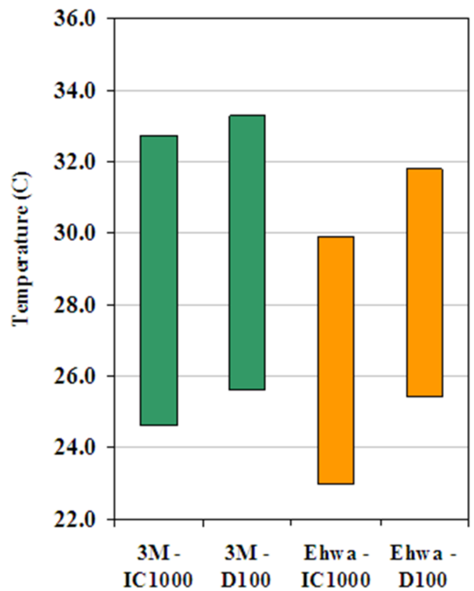
- **Pressure: 1.7 PSI**
- **Sliding velocity: 1.0 m/s**
- **Polishing time (blanket wafers): 1 minute**
- **Slurry: CMC iQ600-Y75 with 30 percent $H_2O_2$ at 300 cc per minute**
- **Conditioning: In-Situ at a down-force of 6 $lb_f$**

# Pads and Diamond Discs Tested



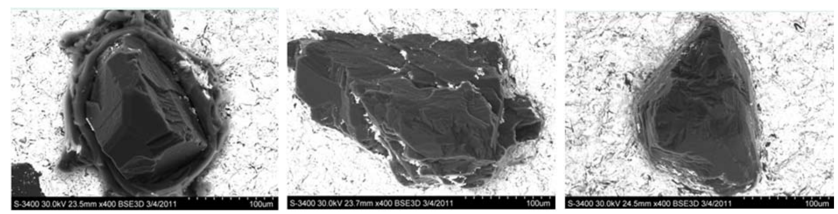



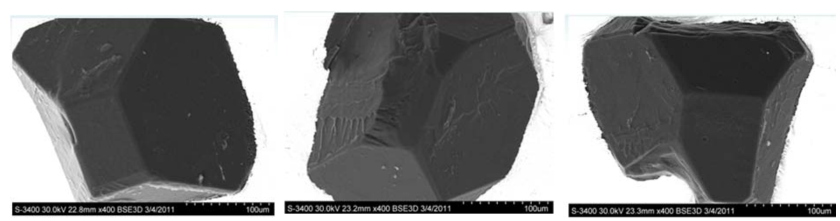




| Disc | Total Surface Furrow Area (micron²) |
|---|---|
| 3M | 3,996 |
| Ehwa | 4,526 |

**Example of 3M's Aggressive Diamonds – Smaller and 'irregular'**

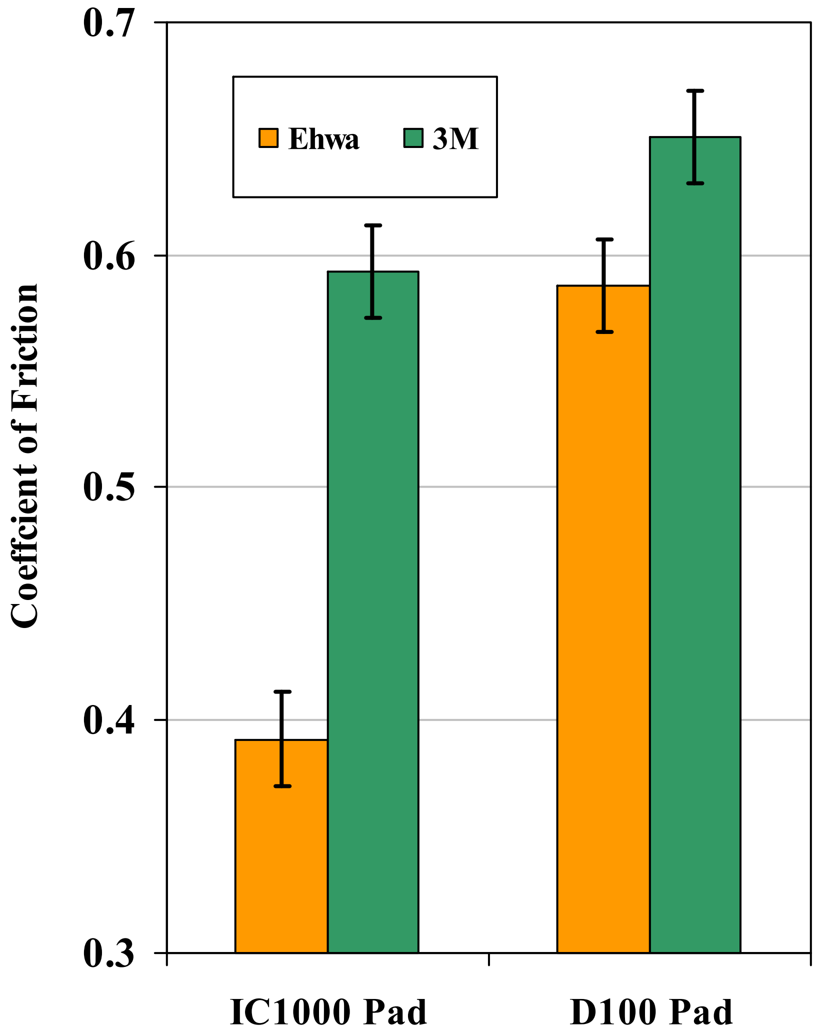


**Example of Ehwa's Aggressive Diamonds – Larger and 'blocky'**



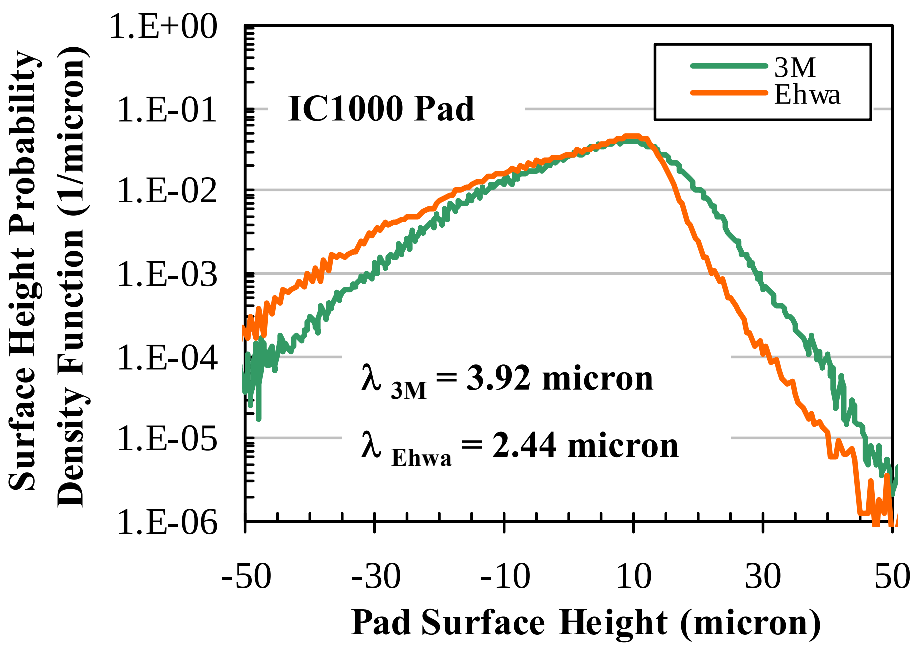
# Coefficient of Friction

## Blanket Wafer Polishing



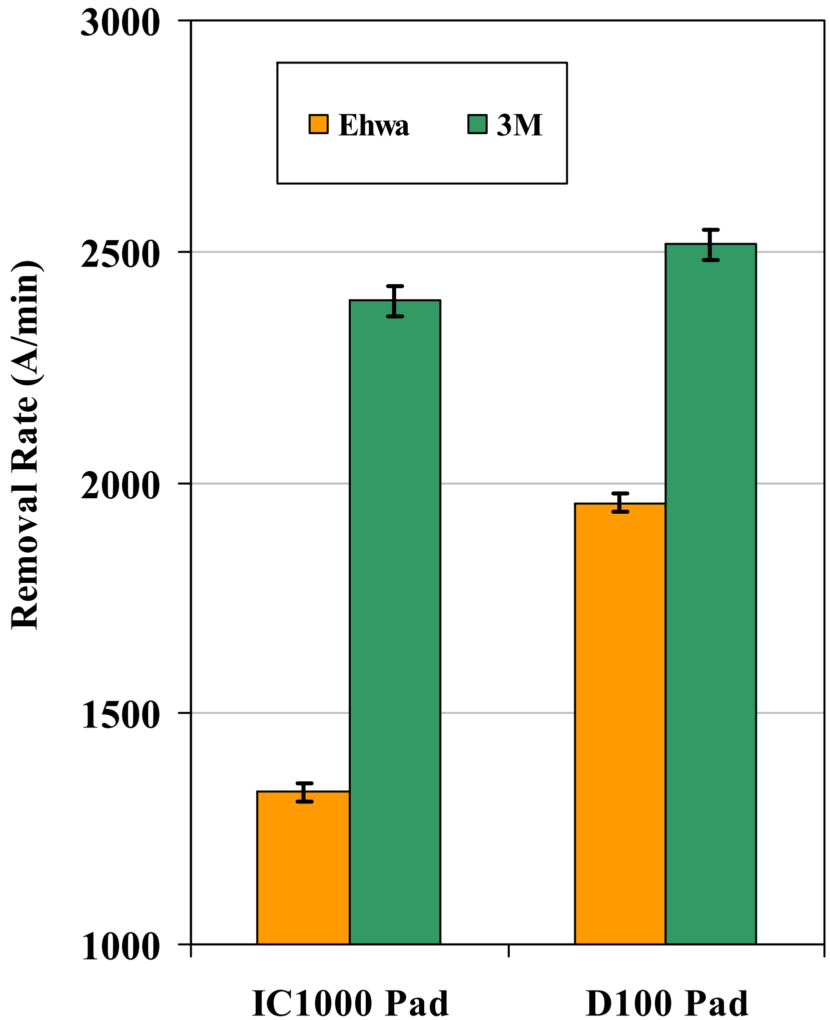

**For both discs, COF for D100 > COF for IC1000.**

**On both pads, COF for 3M > COF for Ehwa. This is due to the fact that λ (surface abruptness, which is a measure of surface height PDF decay length) for 3M is greater than Ehwa (tested only on IC1000).**



# Copper Removal Rate

## Blanket Wafer Polishing




For both discs, RR for D100 > RR for IC1000.

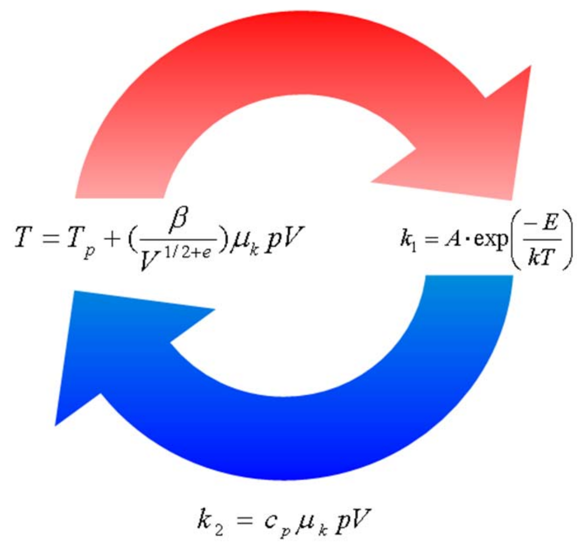
On both pads, RR for 3M > RR for Ehwa.

Above observations consistent with the Langmuir-Hinshelwood mechanism for copper polish (used at ERC with great success over the past 6 years).

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

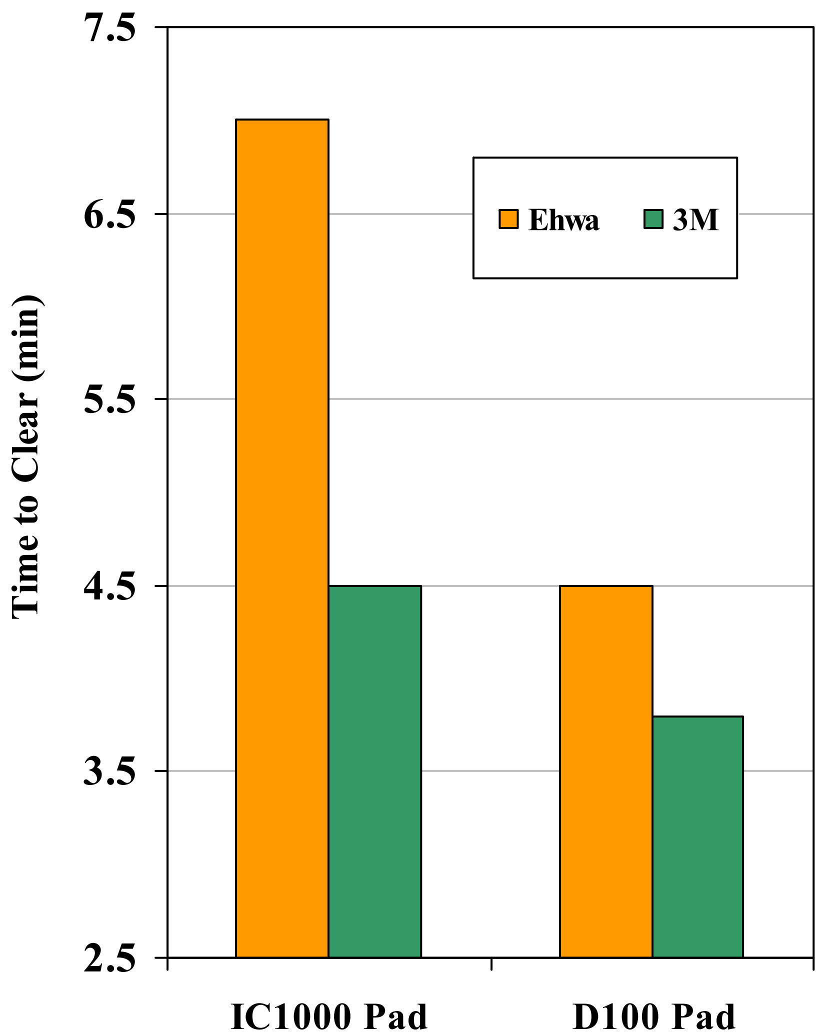
$$\underline{L} \xrightarrow{k_2} L$$

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



# Polishing Time Required for Copper Clearing

## Patterned Wafer Polishing




**For both discs, TTC for D100 < TTC for IC1000.**

**On both pads, TTC for 3M < TTC for Ehwa.**

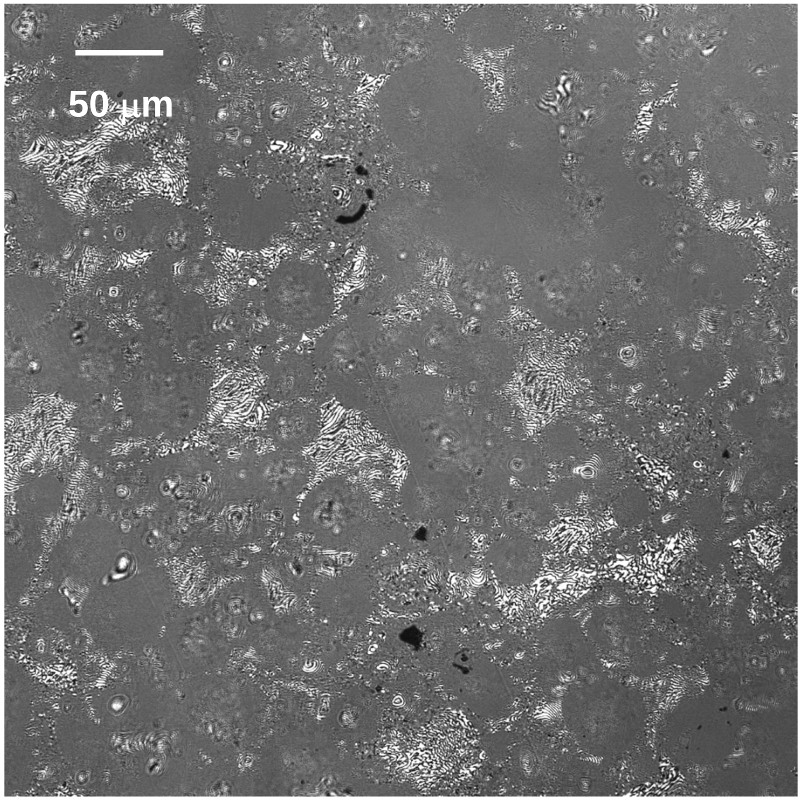
**Above observations are consistent with blanket RR data and are supported by an additional fact that for IC1000:**

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

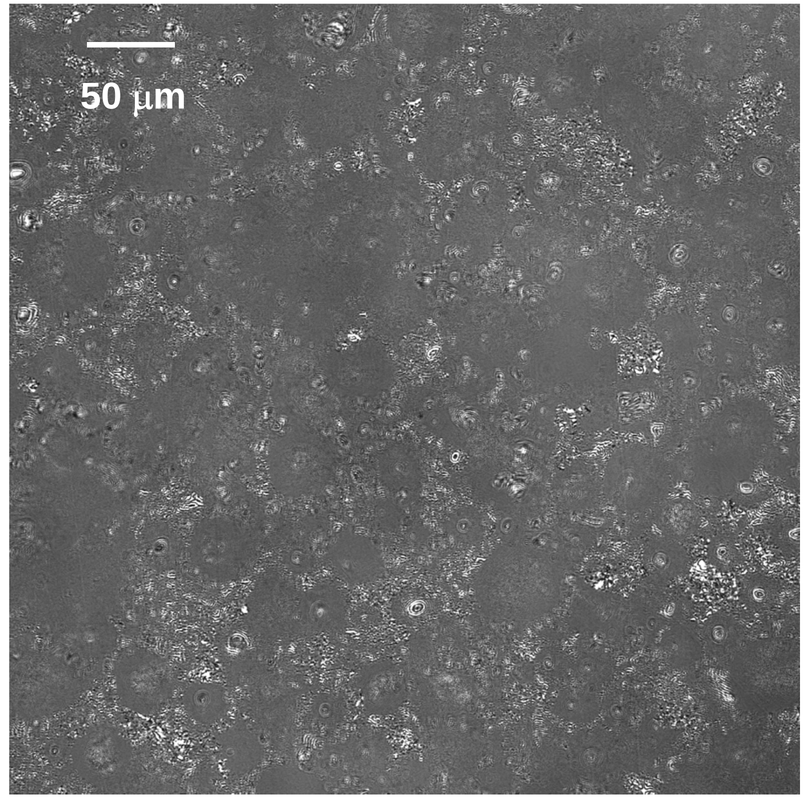
**(b) Near Contact Area (NCA) for Ehwa >> NCA for 3M (therefore more fractured and collapsed pore walls which make the pad surface more lubricated resulting in lower COF and RR for Ehwa). NCA is represented by large 'zebra patterns' (next slide).**

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

## IC1000 Pad




**Ehwa CA = 0.044 percent**

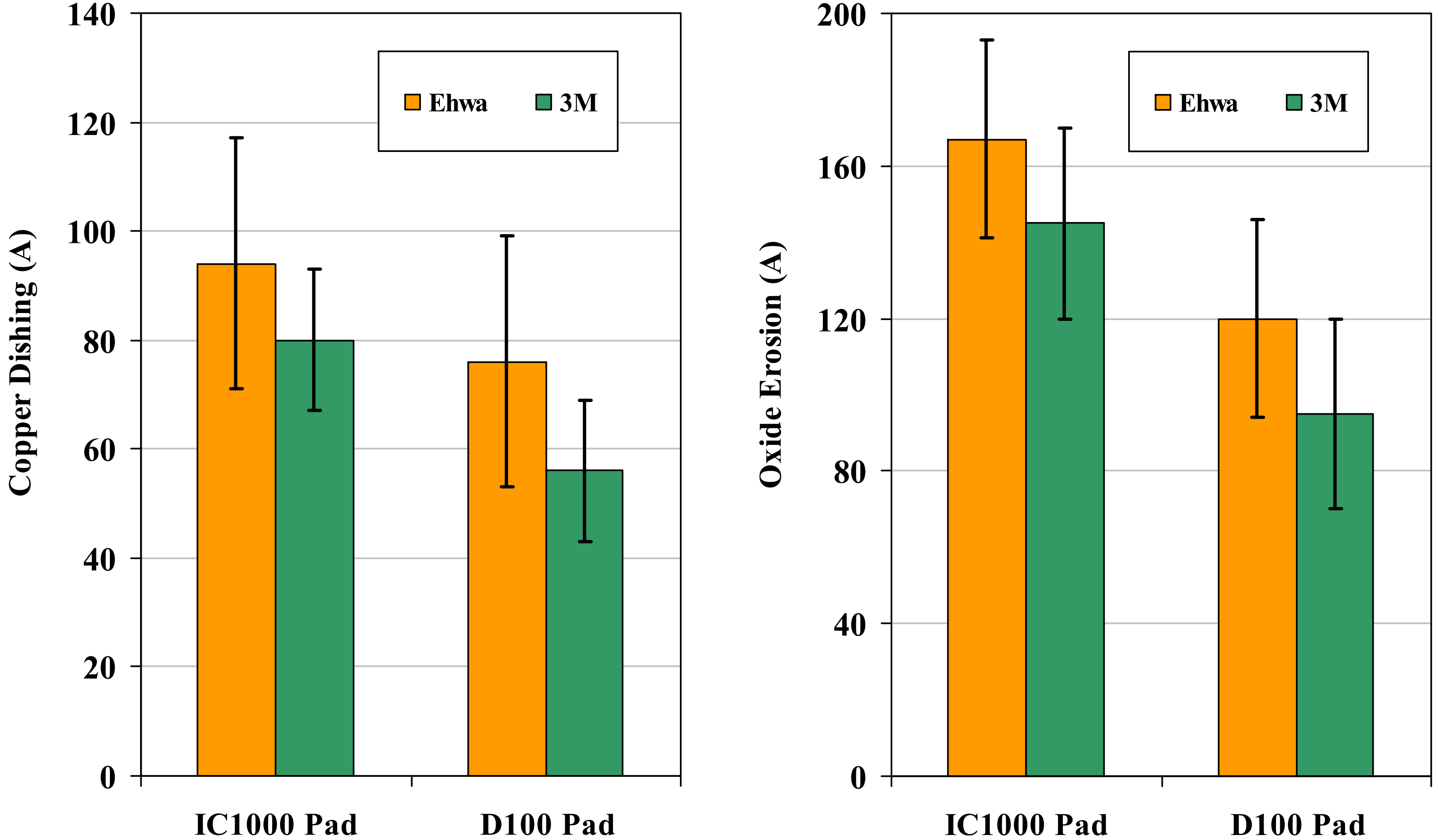



**3M CA = 0.001 percent**

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

# Dishing (left) and Erosion (right) Comparison

## Patterned Wafer Polishing

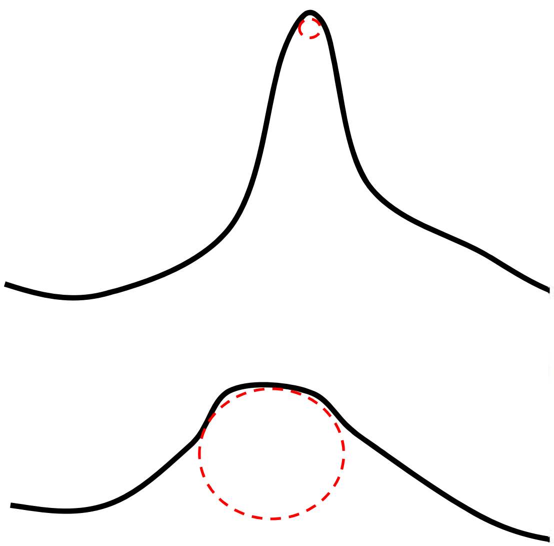


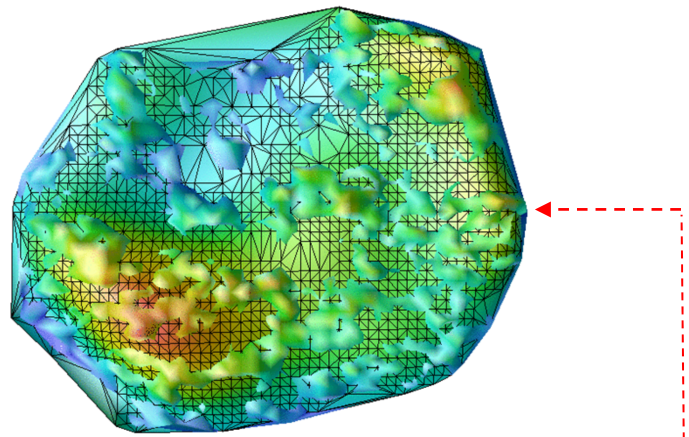
# Pad Summit Curvature from Pad Topography Data

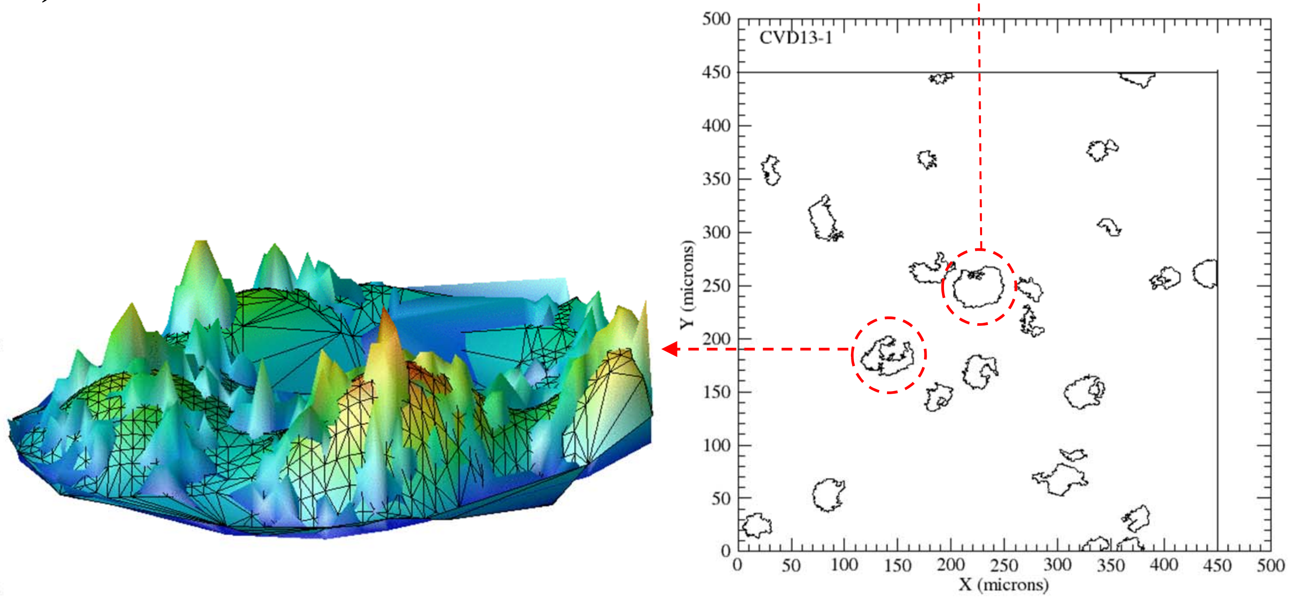
**The radius of curvature (R) at the maximum of a curve is the radius of the best fitting circle at that point.**

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

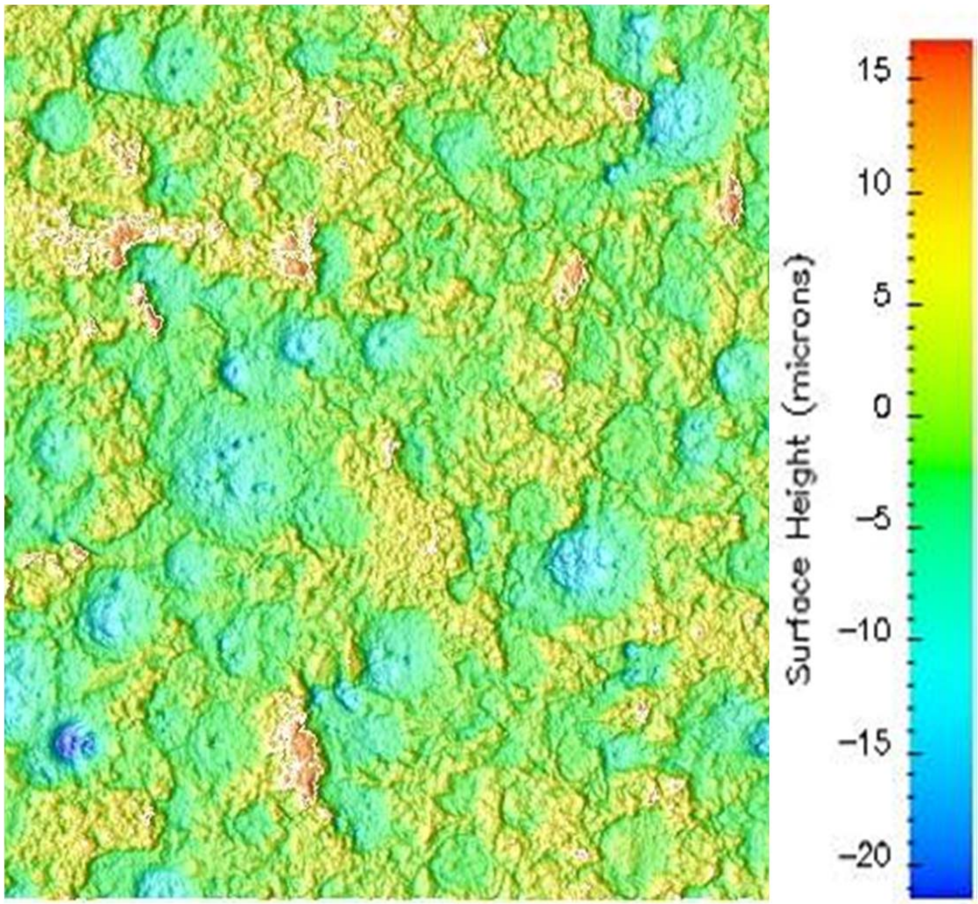
**K = 1/R, so the smaller the radius, the greater the curvature (see below).**







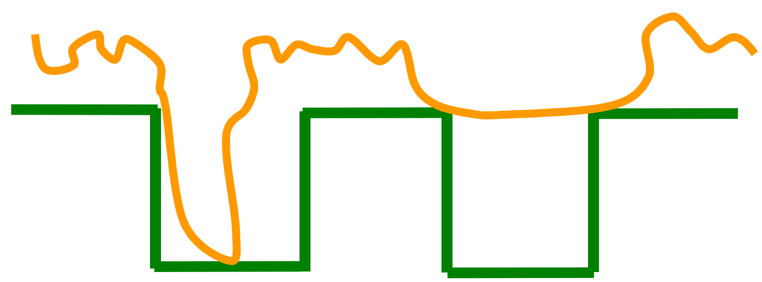
# Dishing and Erosion vs. Summit Curvature




**On the IC1000 pad, 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, D100 pad provided higher COF (by 10 – 50 %) and RR (by 5 – 47 %) than IC1000 for 3M and Ehwa conditioning discs. Consequently, D100 resulted in shorter time-to-clear (by 16 – 36 %) than IC1000 pad during patterned wafer polishing. D100 also resulted in less dishing (by 19 – 30 %) and erosion (by 28 – 34 %) compared to IC1000 for 3M and Ehwa discs.**

- **For blanket copper wafer polishing, 3M disc generated higher COF (by 11 – 51 %) and RR (by 29 – 80 %) than Ehwa disc for both D100 and IC1000 pads. Consequently, 3M resulted in shorter time-to-clear (by 16 – 36 %) than Ehwa disc during patterned wafer polishing. 3M also resulted in less dishing (by 15 – 26 %) and erosion (by 13 to 21 %) compared to Ehwa for both D100 and IC1000 pads.**

- **For IC1000, smaller pad surface contact area and higher surface abruptness generated by the 3M disc resulted in higher copper RR. Sharper asperities generated by Ehwa disc contributed to higher dishing and erosion.**

- **Our EHS objective of attaining 30 percent consumables reduction has been met through pad topography and process contact area tuning.**

# Industrial Interactions, Technology Transfer and Future Plans

**Industrial mentors and contacts:**

- **Don Hooper (Intel)**
- **Mansour Moinpour (Intel)**
- **Cliff Spiro (Cabot Microelectronics)**
- **Peter Ojerholm (Ehwa)**

**Future Plans:**

- **Complete D100 pad surface contact area and topography analysis**
- **Perform same correlations that we did for IC1000 on D100**