Tribological, Thermal and Kinetic Attributes of 300 vs. 450 mm CMP Processes

Y. Jiao [1], X. Liao [1], C. Wu [1], S. Theng [2], Y. Zhuang [1,2], Y. Sampurno [1,2], M. Goldstein [3] and A. Philipossian [1,2]

[1] University of Arizona, Tucson AZ USA
[2] Araca Incorporated, Tucson AZ USA
[3] Intel Corporation, Santa Clara CA USA

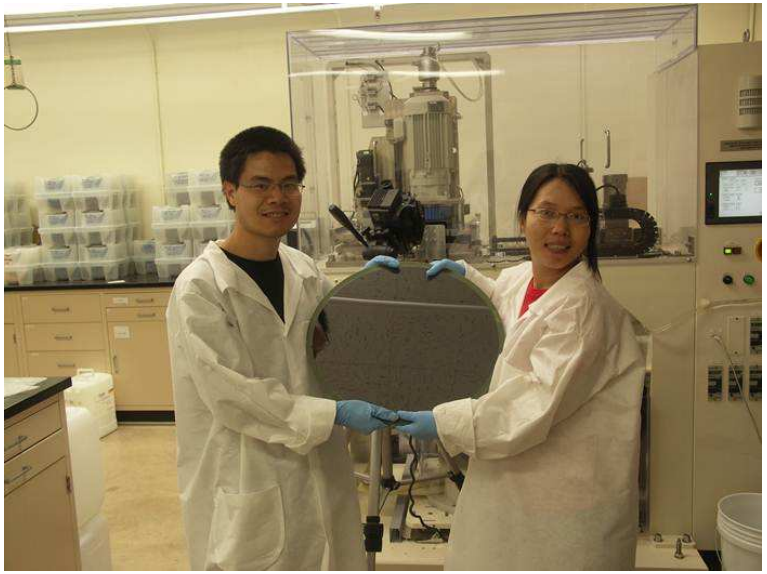
Objectives

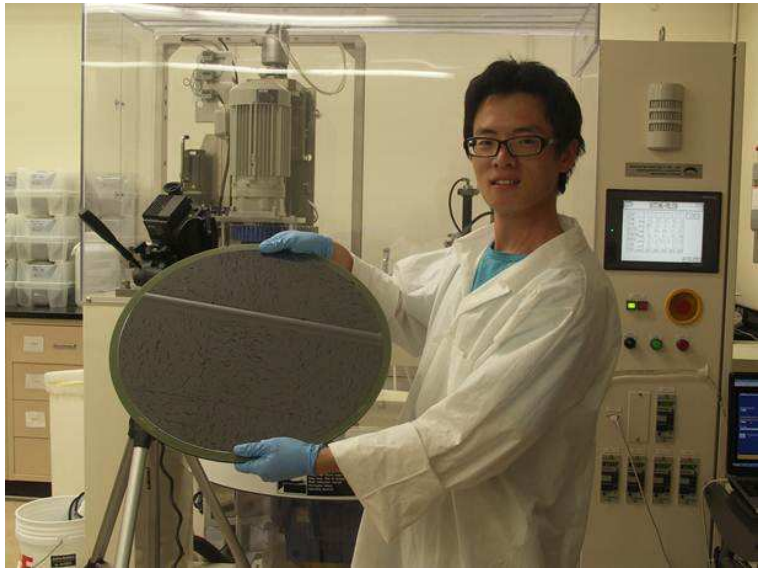
- **Convert a typical 300 mm CMP rotary polisher so that it can process 450 mm wafers.**
- **Compare and contrast the tribological and thermal (i.e. pad surface temperature) characteristics of 300 and 450 mm CMP processes.**
- **Simulate and compare wafer surface temperatures and removal rates between the two systems by coupling their tribological and thermal fingerprints with a highly successful kinetics model for copper CMP.**

Experimental and Theoretical Approach

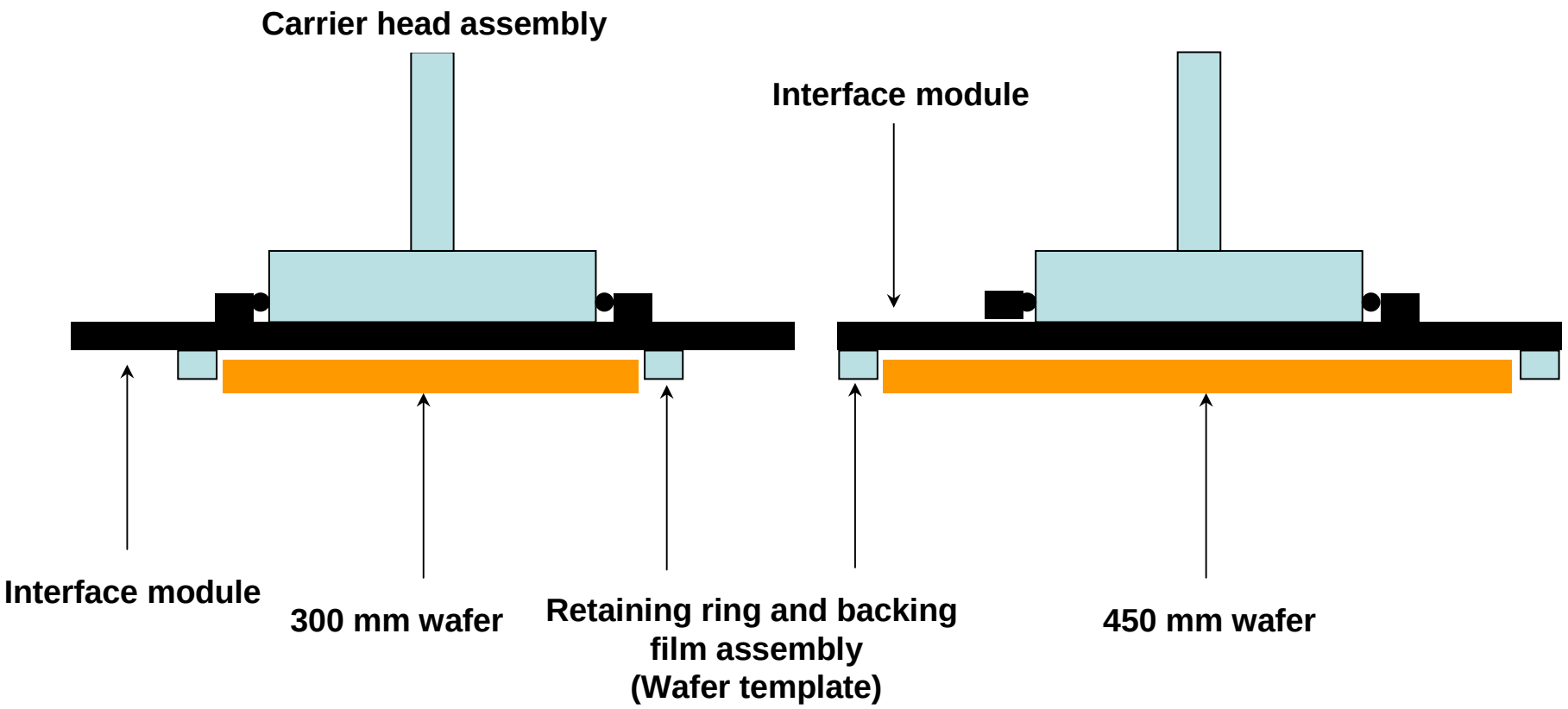
- **Polish 300 and 450 mm bare silicon wafers at 3 pressures and 3 sliding velocities.**
  - **Polisher: Araca APD-800**
  - **Pressure: 1, 2 and 4 PSI**
  - **Sliding velocity: 0.5, 1.0 and 1.5 m/s**
  - **Polishing time: 1 minute**
  - **Pad: D100 concentrically grooved pad**
  - **Slurry: Fujimi PL4217 fumed silica slurry at 300 ml/min**
  - **Conditioning: Ex-Situ at a down-force of 10 lb_f**
- **Perform two 85-second polishing runs with continuously varied pressures and sliding velocities to generate the Stribeck curve in a highly cost-effective way.**
- **Simulate the wafer surface reaction temperature and copper removal rate using a 2-step modified Langmuir-Hinshelwood (LH) model based on previously successful simulation parameters.**

450 mm Bare Silicon Wafer

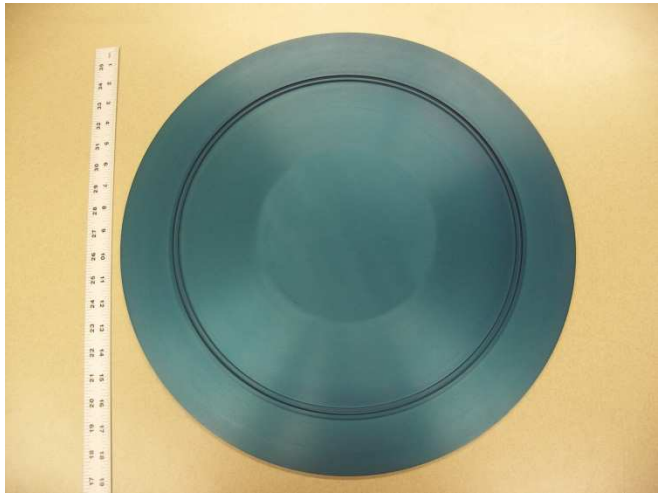


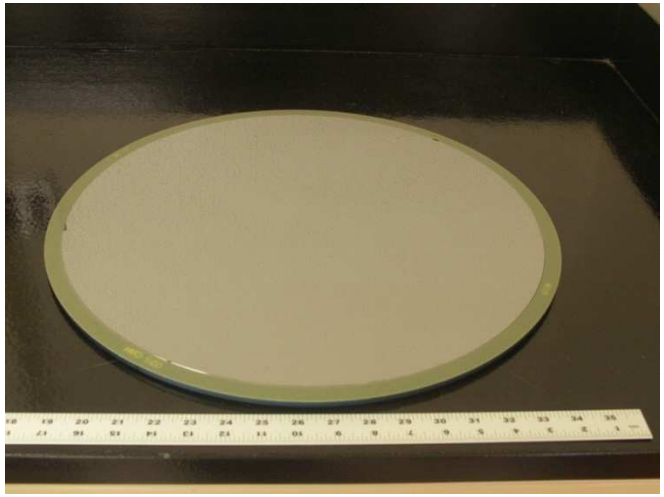


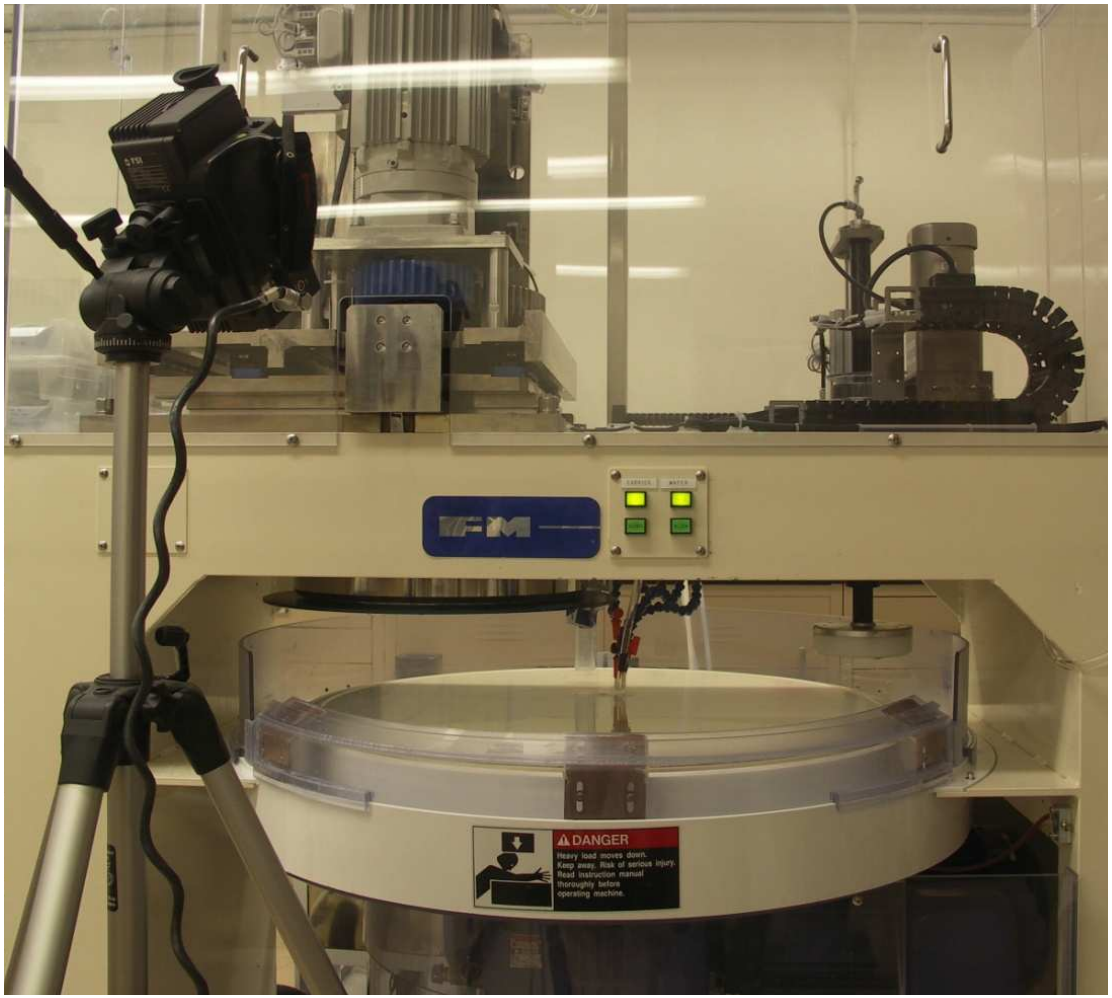
Interface Module for 300 (left) & 450 mm (right) Wafers



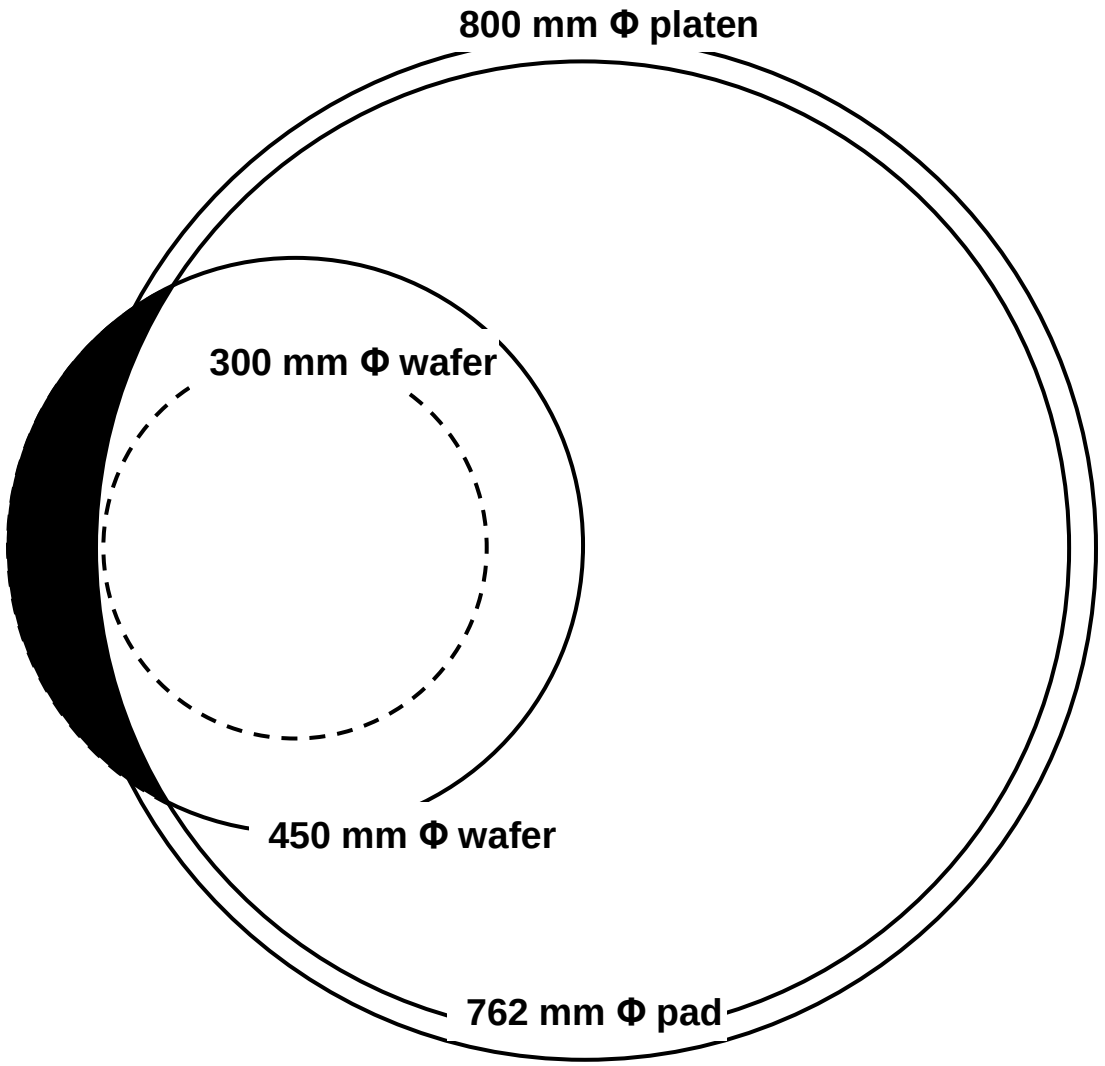
Interface Module, Wafer Template (with Wafer) and Experimental Set-up







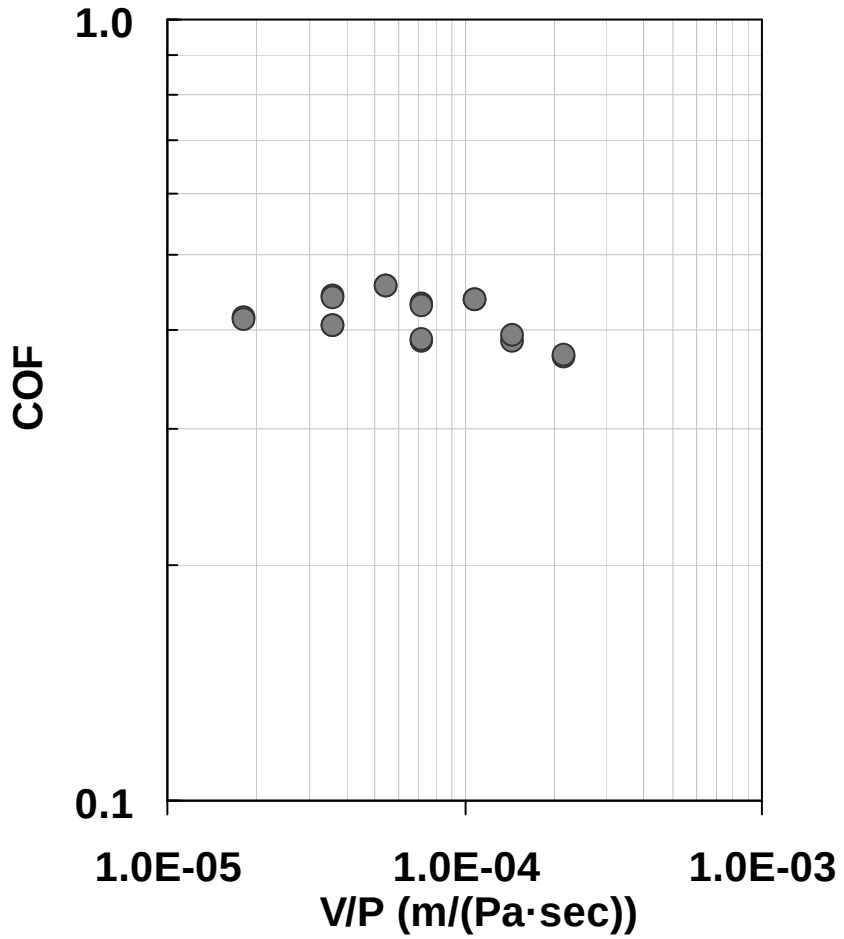
Schematic of Wafer Positions Relative to Pad & Platen

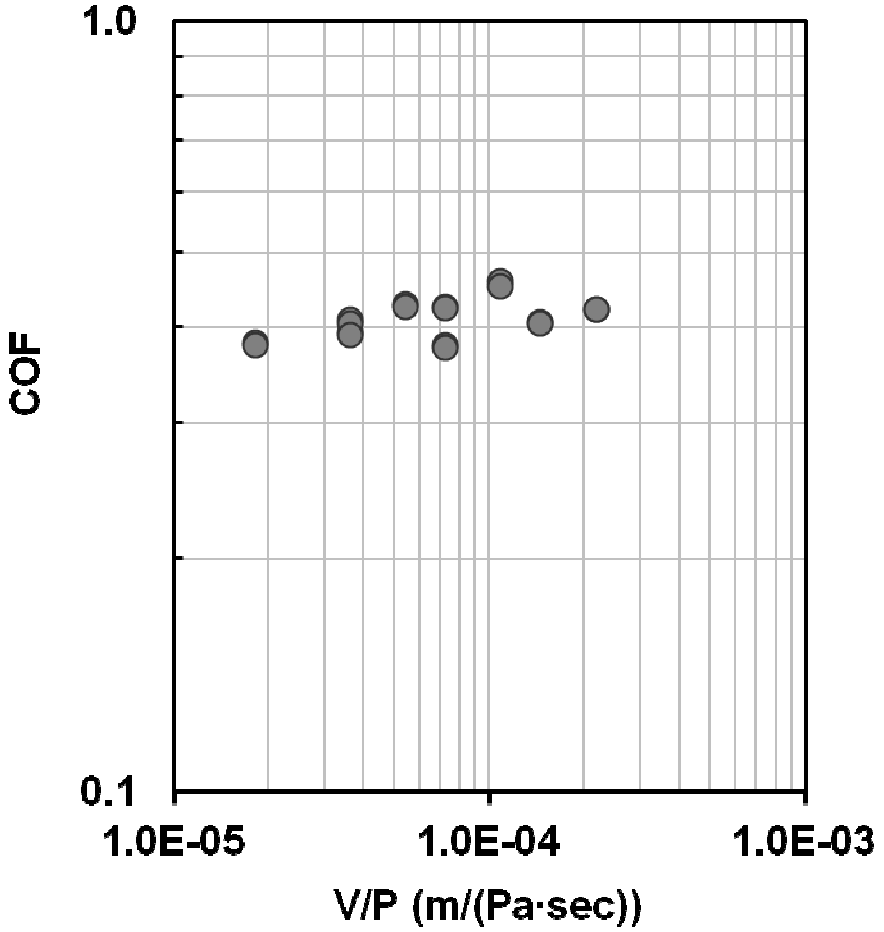


For 450 mm system, approximately 13.7% of the wafer hangs off the edge of the pad and does not contact the pad during polishing.

Stribeck Curves for 300 (left) & 450 mm (right) Systems

based on 18 Individual 1-minute runs

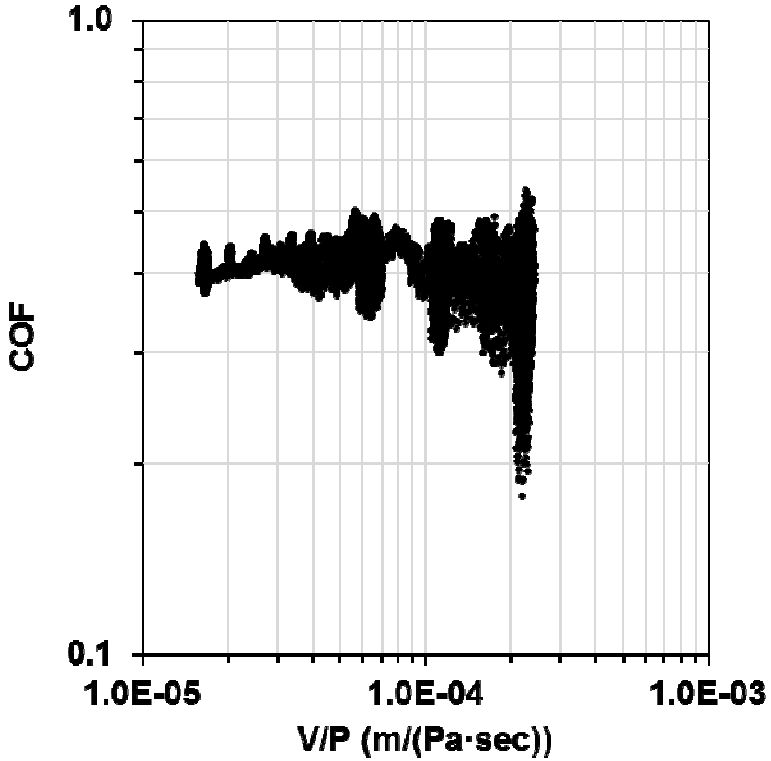


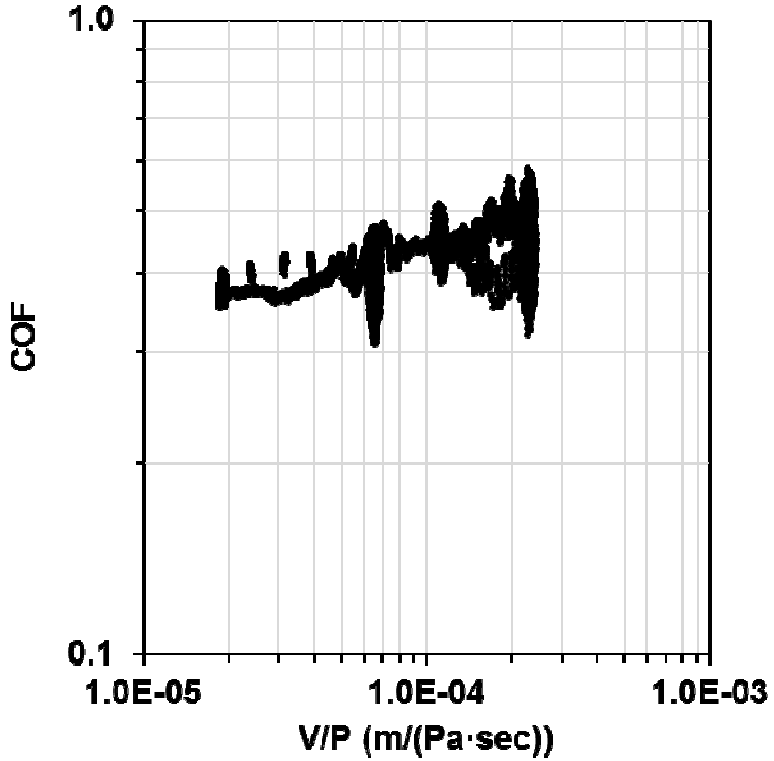


Both systems exhibit boundary lubrication behavior across the range of velocities and pressures investigated.

Stribeck Curves for 300 (left) & 450 mm (right) Systems

based on only ONE multi-condition 85-second run





Step No.	Pressure (KPa)	Sliding Velocity (m/s)	Time (Sec)
1	P2 = 13.79	V3 = 1.5	T = 20
2	P1 = 6.89	V3 = 1.5	T = 15
3	P3 = 27.58	V3 = 1.5	T = 15
4	P3 = 27.58	V1 = 0.5	T = 15
5	P1 = 6.89	V1 = 0.5	T = 20

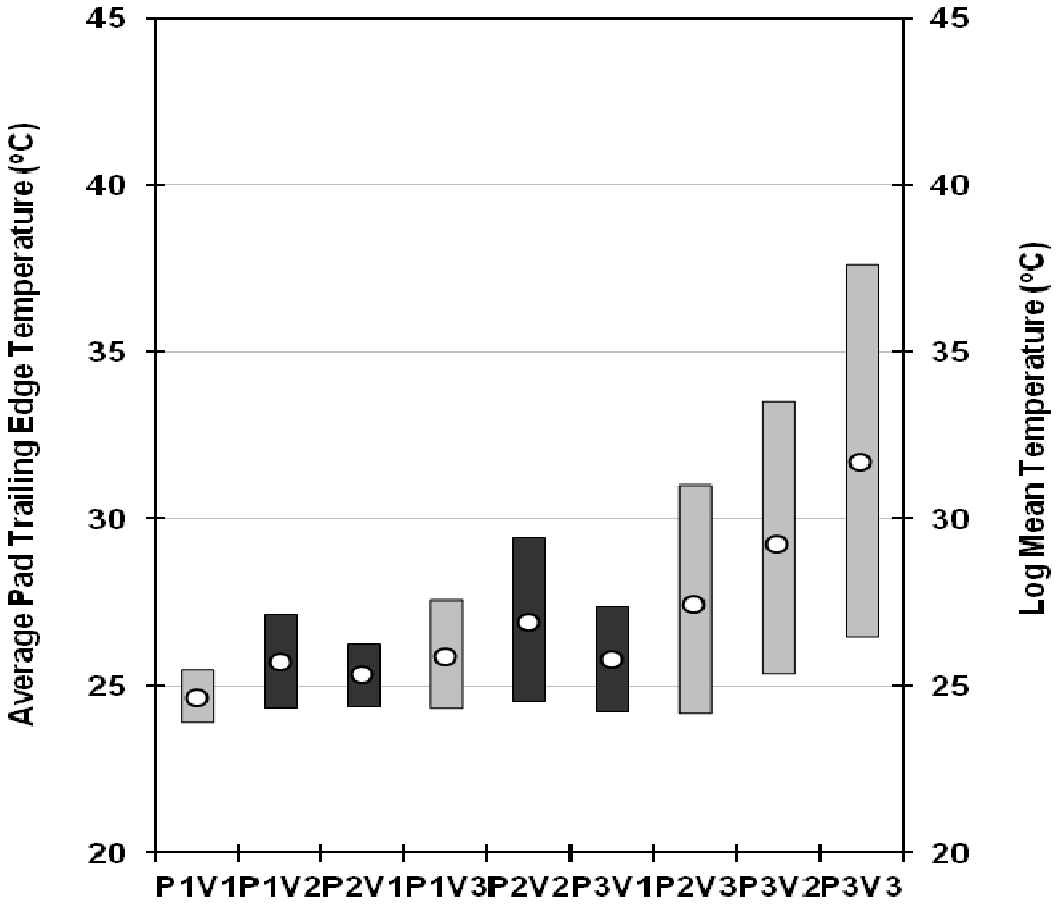
Log Mean Temperature (LMT)

$$LMT = \frac{(T_{55} - T_{ref}) - (T_5 - T_{ref})}{\ln\left(\frac{T_{55} - T_{ref}}{T_5 - T_{ref}}\right)}$$

T_5 and T_{55} are the average trailing edge pad surface temperatures near the beginning (5 sec) and the end (55 sec) of the polishing step, respectively.

T_{ref} is the reference temperature and is taken as 0 ºC here.

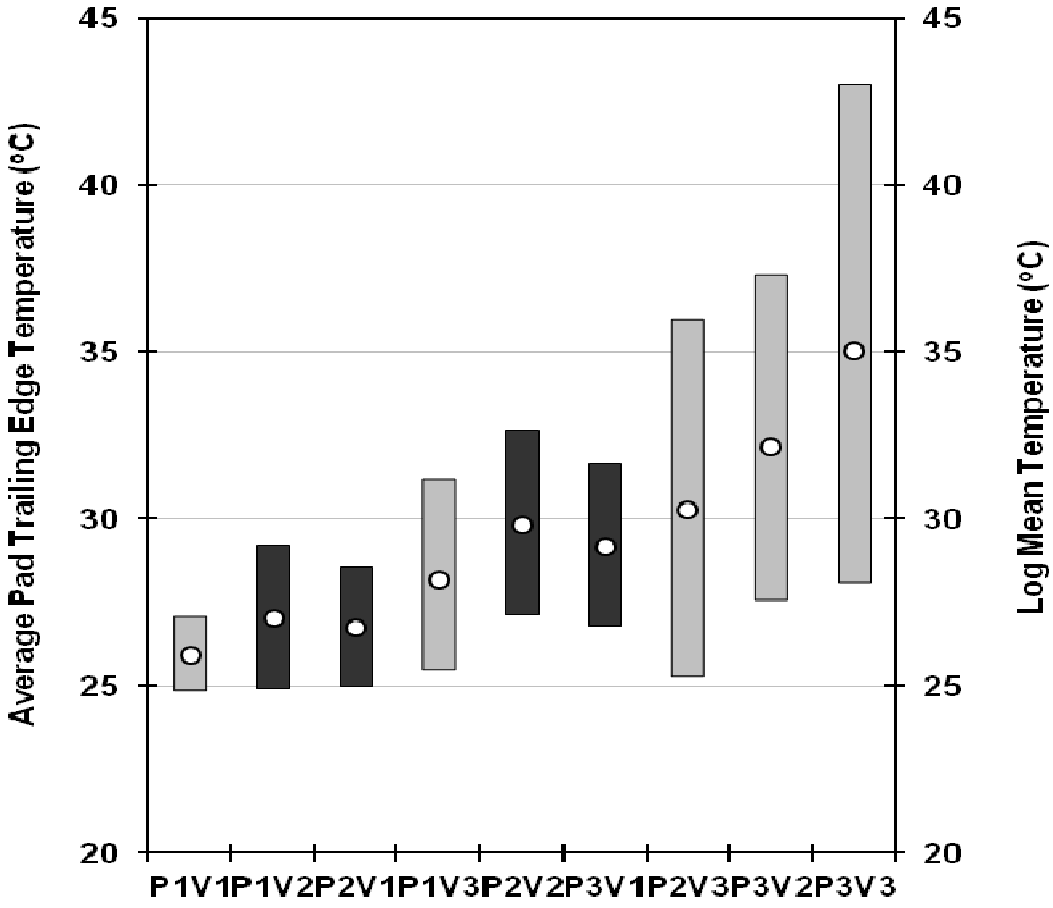
Average Pad Trailing Edge Temperatures & LMT for the 300 mm System



Pressure (KPa)	Sliding Velocity (m/s)
P1 = 6.89	V1 = 0.5
P2 = 13.79	V2 = 1.0
P3 = 27.58	V3 = 1.5

Higher values of P×V produce higher values of LMT.
Average pad surface temperature can rise by as much as 12 °C during 1-min polishing run.

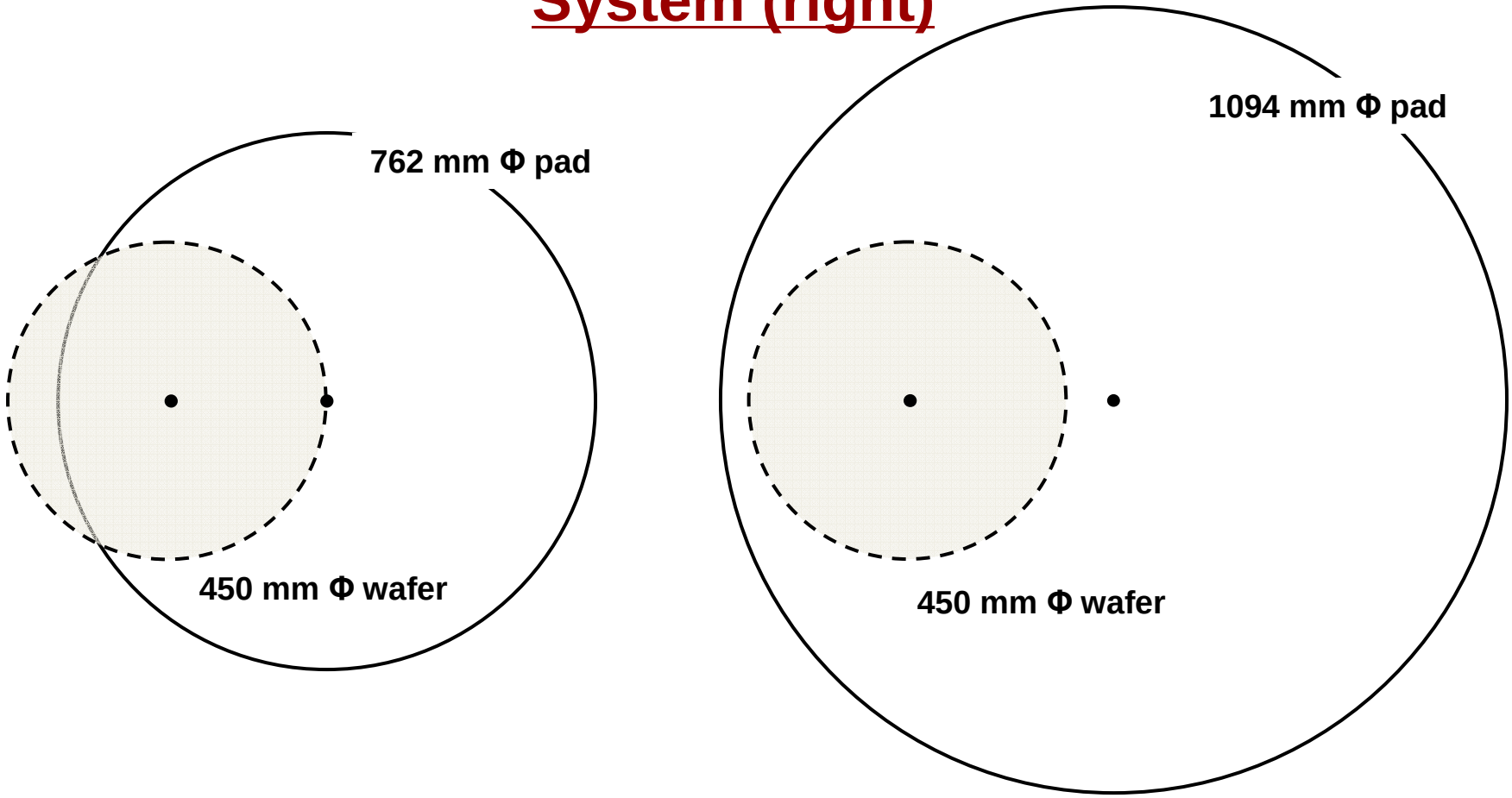
Average Pad Trailing Edge Temperatures & LMT for the 450 mm System



Pressure (KPa)	Sliding Velocity (m/s)
P1 = 6.89	V1 = 0.5
P2 = 13.79	V2 = 1.0
P3 = 27.58	V3 = 1.5

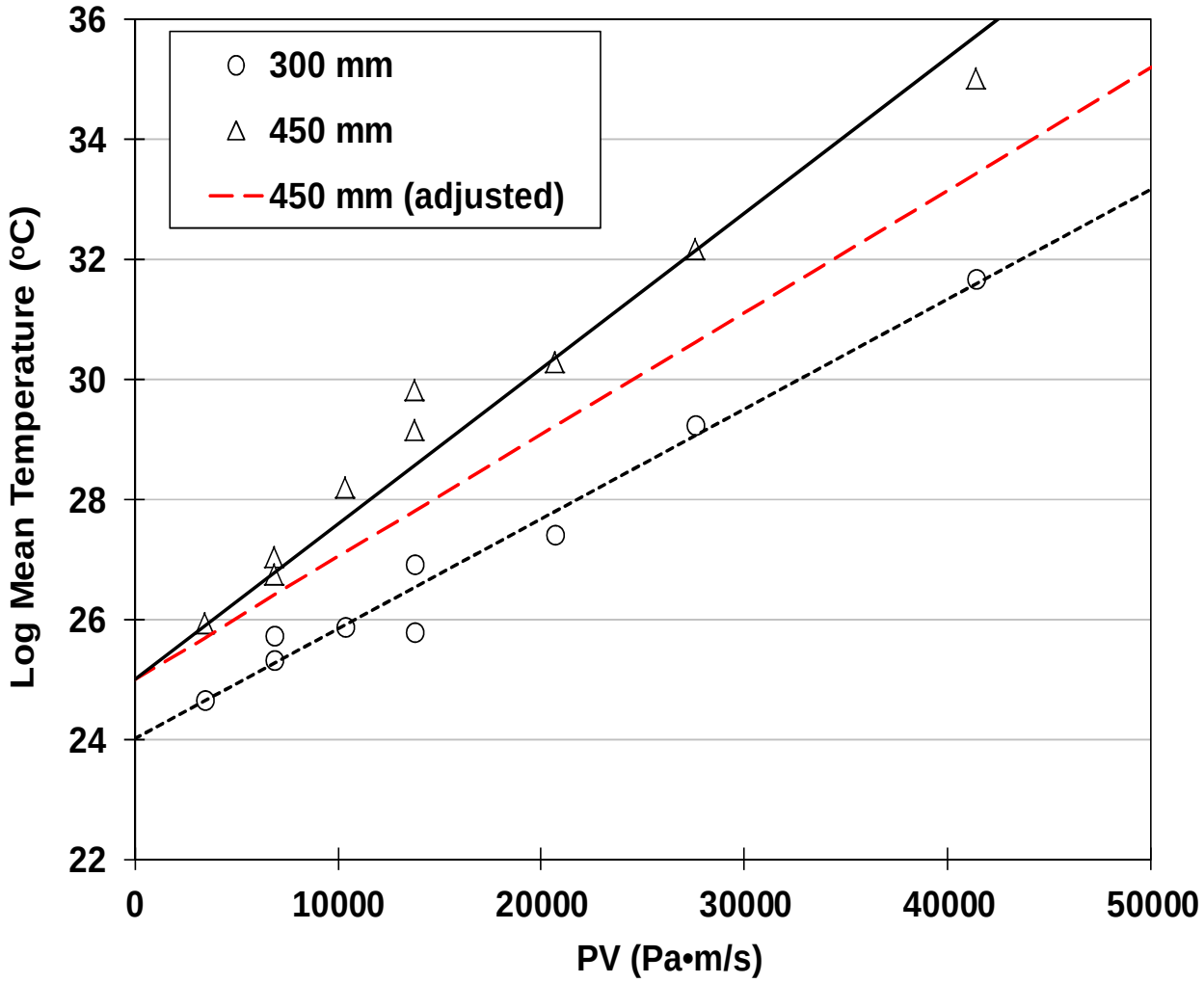
Higher values of P×V produce higher values of LMT.
Average pad surface temperature can rise by as much as 15 °C during a 1-min polishing run.

Our 450 mm System (left) vs. an Actual 450 mm System (right)



In an actual 450 mm polisher, to achieve a sliding velocity of 1 m/s, the platen needs to rotate at 33 RPM. Whereas, in our system, platen rotation needs to be at 42 RPM to compensate for its smaller diameter. This higher rotation rate causes the temperature to rise further in our system. Therefore a temperature adjustment is needed for fair comparison (see next page).

LMT for 300 & 450 mm Systems



A straight line relationship exists between the two factors with the 450 mm system having a steeper slope.

Based on the adjusted line, a 450 mm system will operate only slightly warmer (by 1 - 2 °C).

Removal Rate Model

- **Modified Langmuir-Hinshelwood (LH) model:**
  - **n moles of reactant R in the slurry react at rate k_1 with copper film on the wafer to form a product layer L on the surface**

$$\underline{Cu} + nR \xrightarrow{k_1} \underline{L} \qquad \boxed{k_1 = A \times \exp(-E_a / kT)} \qquad \boxed{T = T_p + \frac{\beta}{V^{0.5+e}} \times COF \times p \times V}$$

  - **Product layer $\underline{L}$ is subsequently removed by mechanical abrasion with rate k_2**

$$\underline{L} \xrightarrow{k_2} L \qquad \boxed{k_2 = C_p \times COF \times p \times V}$$

  - **Abraded material *L* is carried away by the slurry**

- **RR in this sequential mechanism therefore is a function of both chemical and mechanical attributes of the process**

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

Fitting Parameters for the LH Model

E_a	Activation Energy (eV)
A	Pre-exponential factor of chemical rate constant (mole $\times$ m^{-2} s^{-1})
C_p	Proportionality constant for the mechanical rate constant (mole/J)
e	Exponential factor for sliding velocity derived from pad heat partition fraction
β	A constant that depends on wafer size, tool geometry and pad surface and bulk properties ($K/Pa \cdot (m/s)^{e-0.5}$)

ζ (zeta) for Different CMP Systems

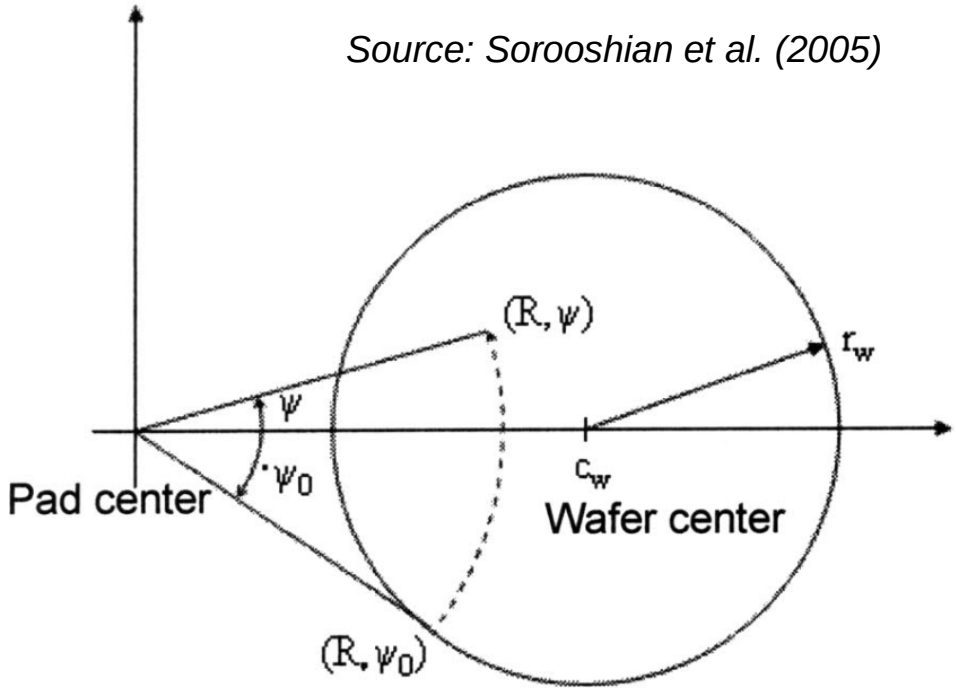
β is proportional to ζ.

$$\beta = \frac{2\zeta\gamma_p p_a / p}{\sqrt{\pi\kappa\rho C_p}}$$

ζ depends on tool geometry and wafer size, and is a function of r_w and c_w.

$$\zeta = \frac{2c_w^{1/2}}{3\pi r_w^2}\int_{c_w-r_w}^{c_w+r_w} R(2\psi_0)^{3/2}dR$$

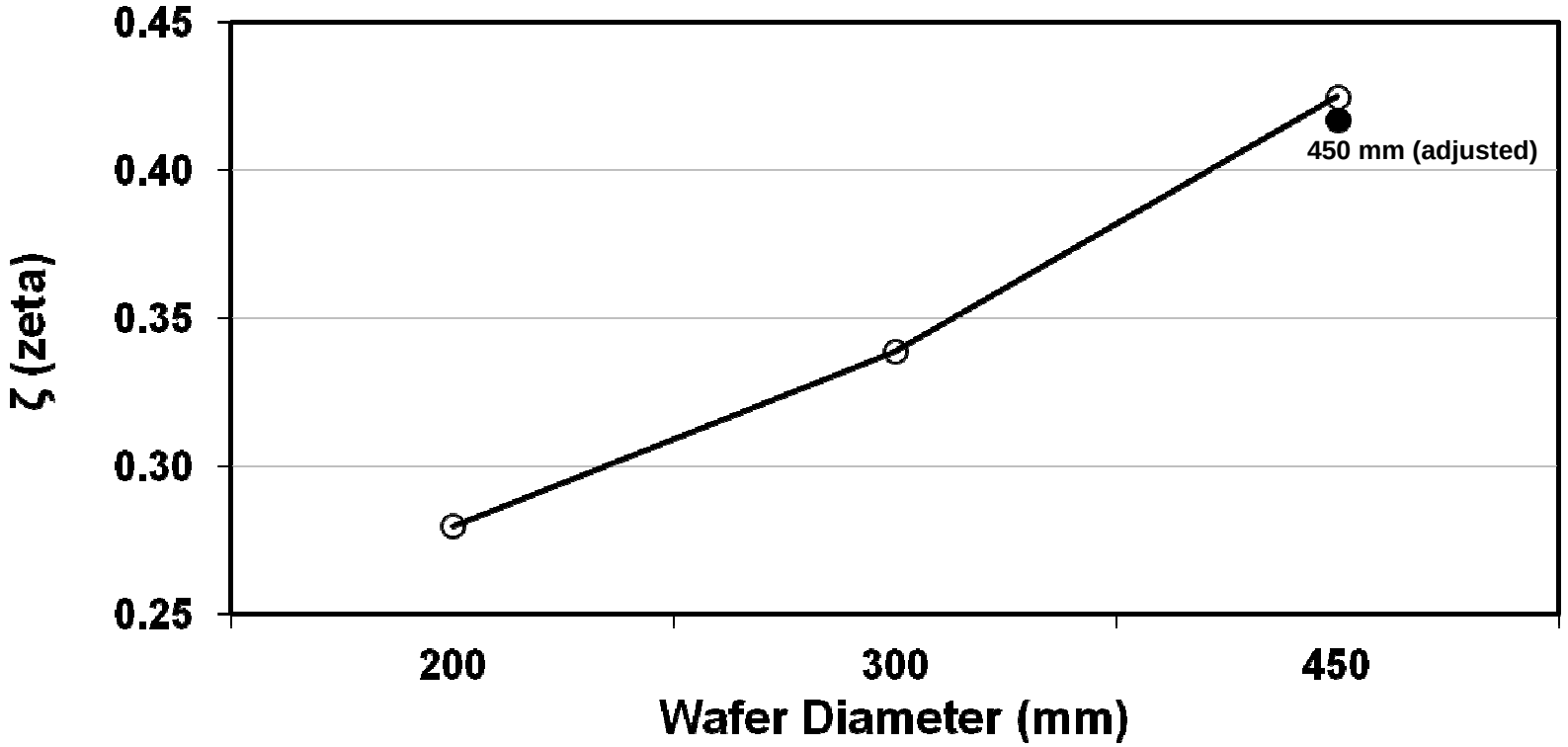
Source: Sorooshian et al. (2005)



where r_w and c_w are wafer radius and distance between wafer center and pad center, respectively.

So we can get the ζ values by solving the integral for different CMP systems.

ζ (zeta) for Different CMP Systems



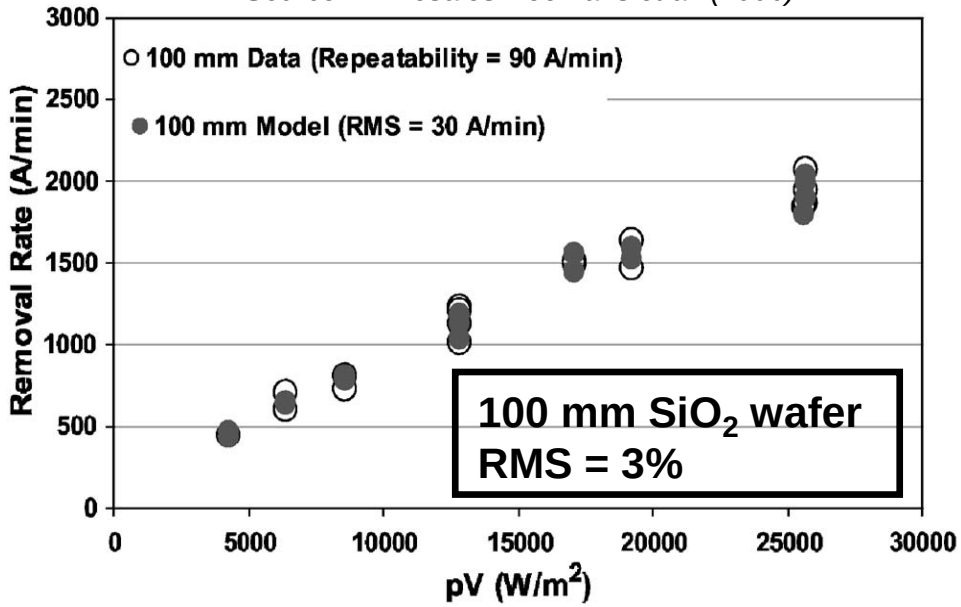
	200 mm	300 mm	450 mm	450 mm (adjusted)
r_w (mm)	100	150	225	225
c_w (mm)	114	225	225	290
ζ	0.280	0.339	0.425	0.417

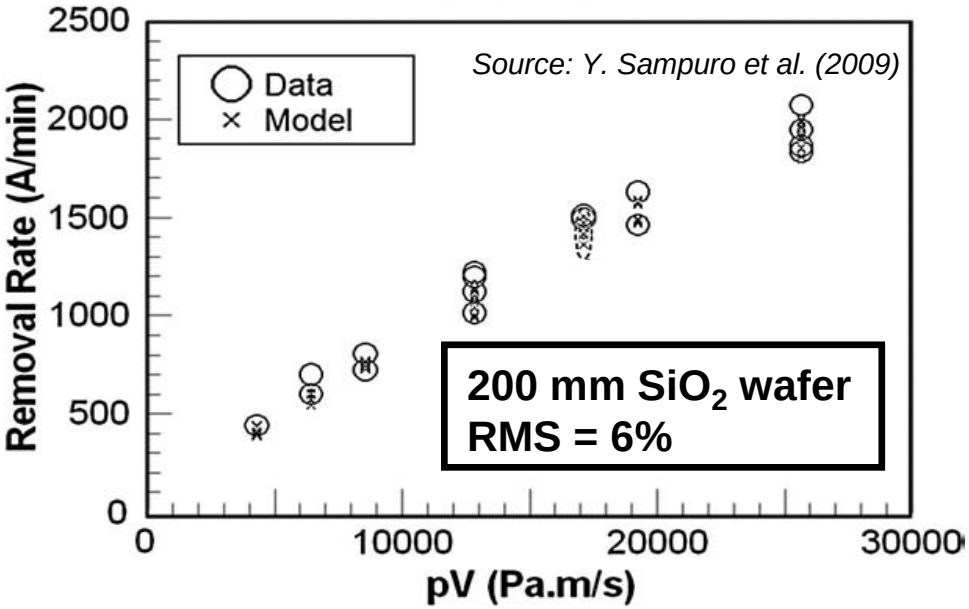
Optimal Values for the Simulation Parameters

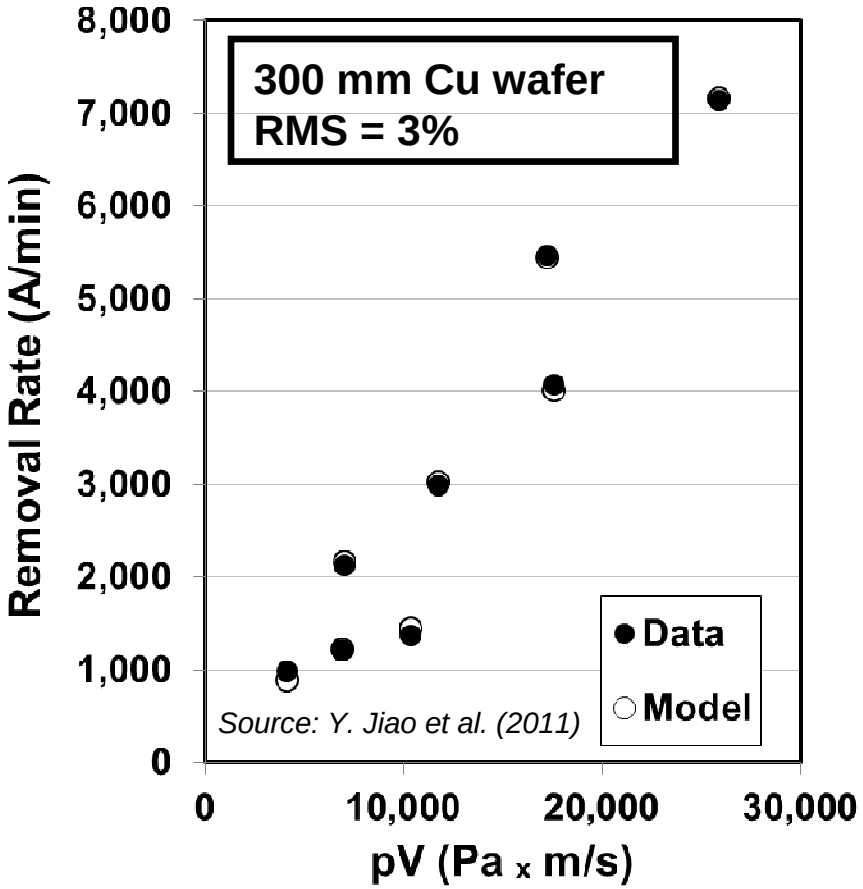
	300 mm	450 mm	450 mm (adjusted)
E **(eV)**	1.2	1.2	1.2
A **(mole·m^{-2}·s^{-1})**	5.39×10^{16}	5.39×10^{16}	5.39×10^{16}
C_p **(mole/J)**	2.26×10^{-7}	2.26×10^{-7}	2.26×10^{-7}
β **(K/Pa·(m/s)$^{e-0.5}$)**	**0.80×10^{-3}**	**1.00×10^{-3}**	**0.98×10^{-3}**
e	0.76	0.76	0.76

Successful Implementation of our LH RR Model

Source: D. Rosales-Yeomans et al. (2006)

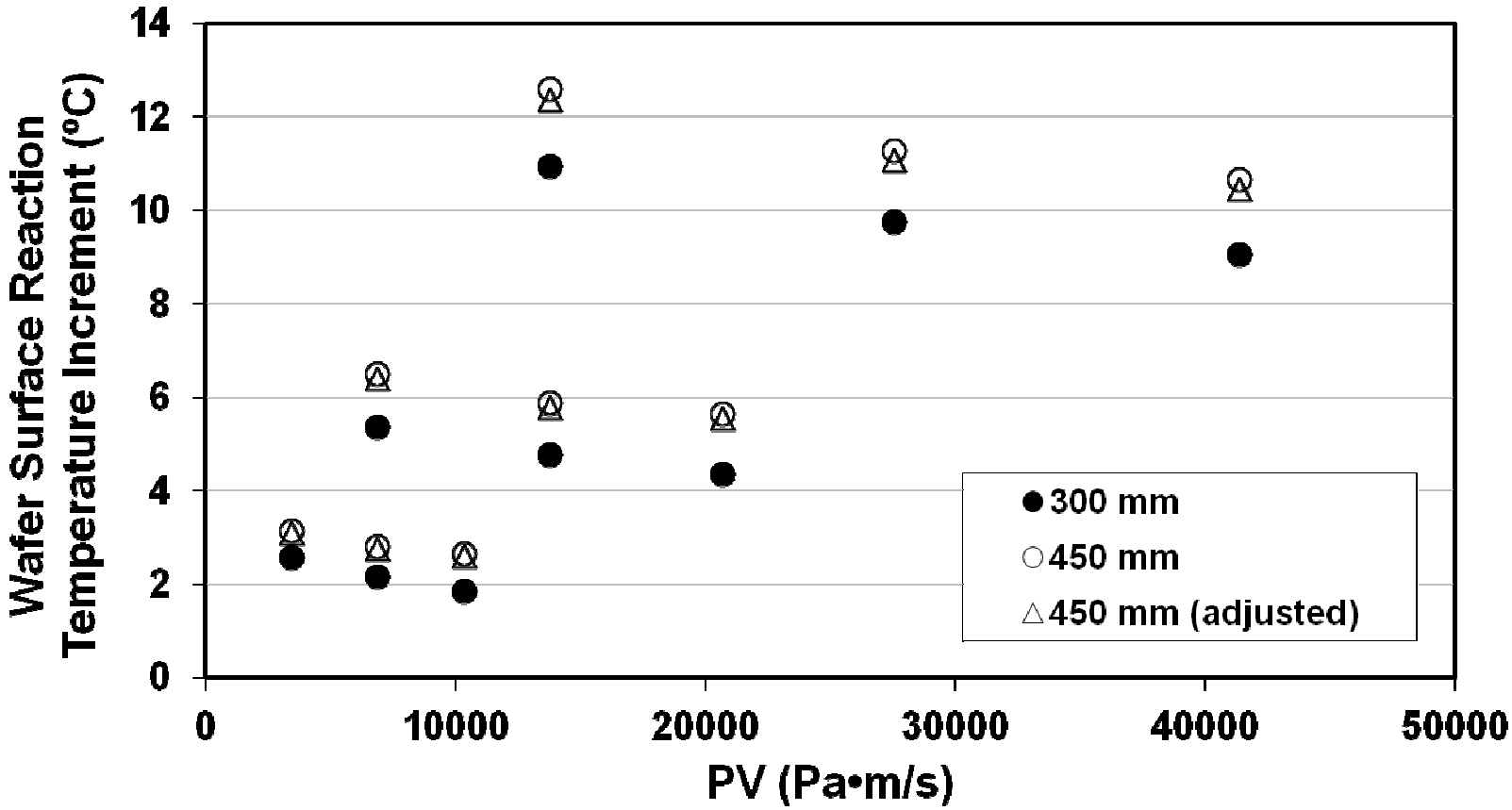






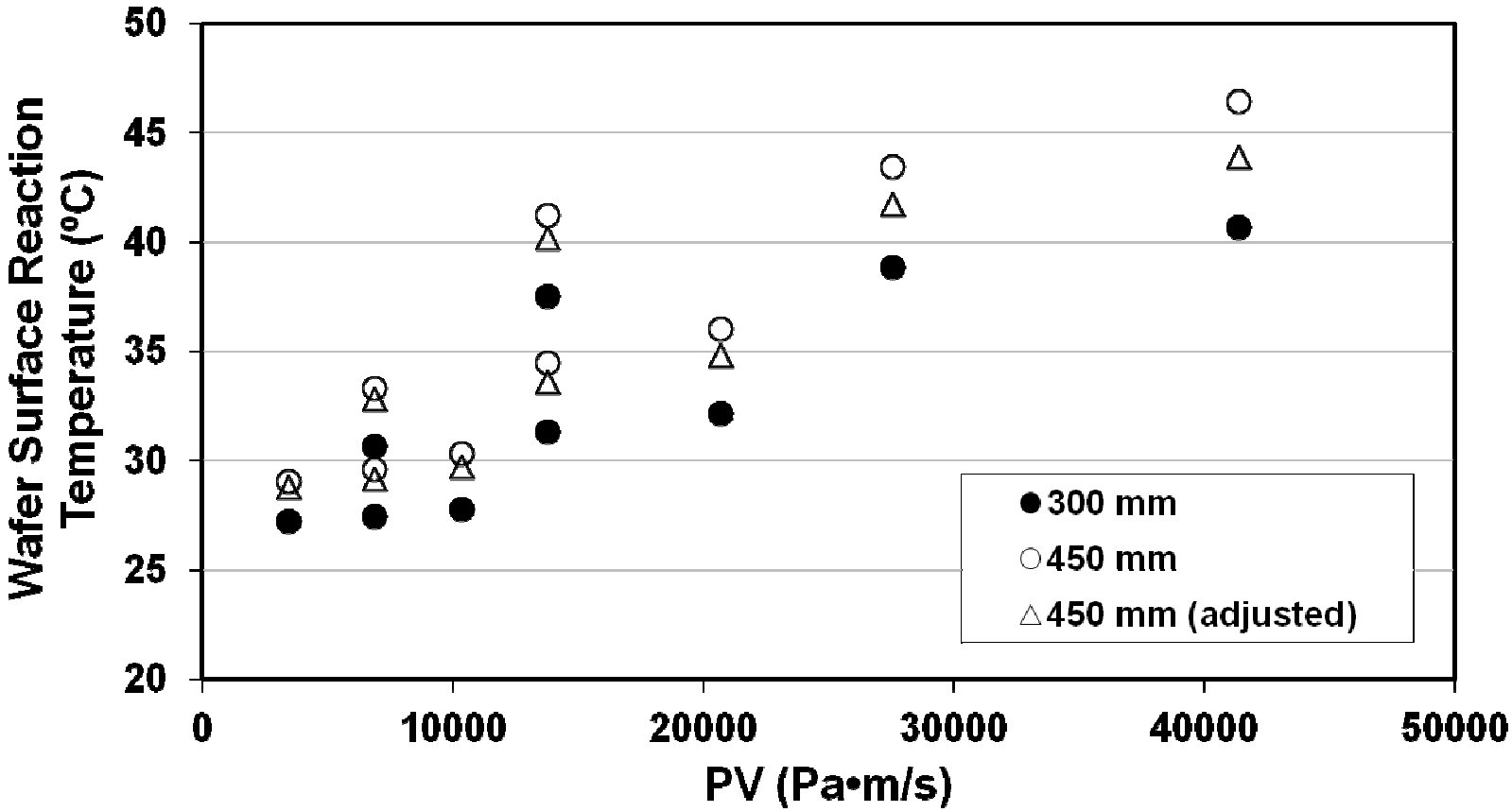
RMS : Root mean square error between experimental and simulated RR values

Simulated Wafer Surface Reaction Temperature Increment



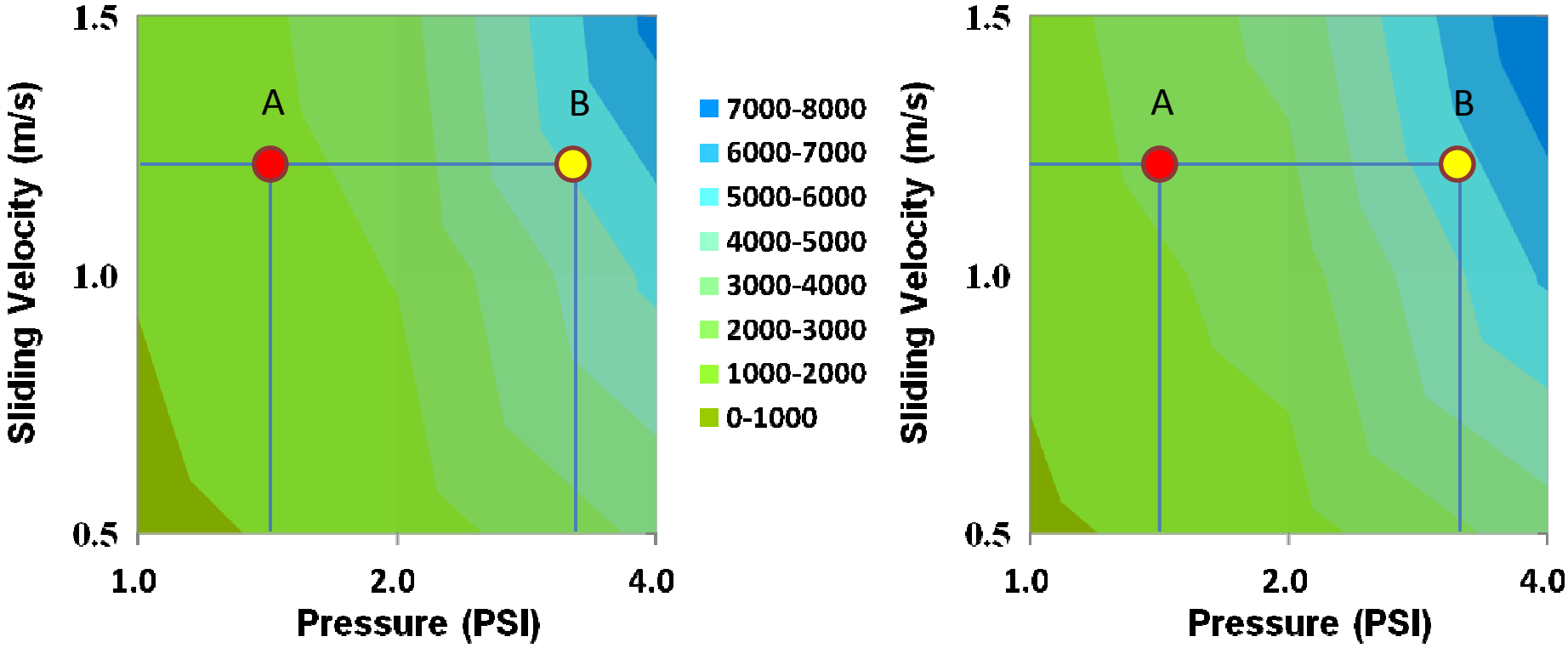
Simulated T inc $_{450}$ > Simulated T inc $_{450\text{-adj}}$ > Simulated T inc $_{300}$

Wafer Surface Reaction Temperature



Simulated Reaction T_{450} > Simulated Reaction $T_{450\text{-}adj}$ > Simulated Reaction T_{300}

Lim-Ashby Plots of Simulated Copper RR (A/min) for 300 mm (left) & 450 mm 'Adjusted' (right) Wafers



Pressure dominates RR at most conditions.

'Point A' – At 1.2 m/s & 1.5 PSI, Cu RR for 450 mm is 18% higher than 300 mm
'Point B' – At 1.2 m/s & 3.5 PSI, RR is 22% higher than 300 mm

Summary

- **Within the ranges of parameter investigated, the two systems behave similarly in terms of their coefficients of friction and lubrication regimes.**

- **The 450 mm process, once adjusted for its platen velocity, runs only slightly warmer (by 1 – 2 ºC) than its 300 mm counterpart.**

- **Based on experimental data and Cu RR simulations, the wafer surface reaction temperature for the 450 mm process is higher (by 2 – 3 ºC) than the 300 mm process.**

- **Simulated Cu RRs for the 450 mm process are higher by 8 to 31 percent compared to those for the 300 mm process.**

- **It is expected that a smooth transition can be achieved by IC makers when scaling up to 450 mm wafers, however thermal and frictional considerations will be critical as they dictate RR increases that can be expected from a direct recipe transfer.**