

Application of Shear Force Spectral Analysis in STI CMP

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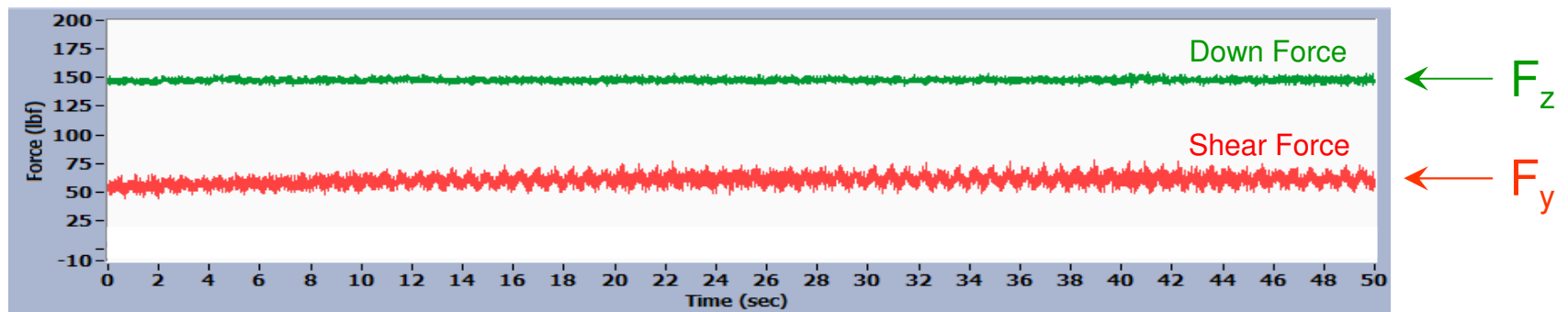
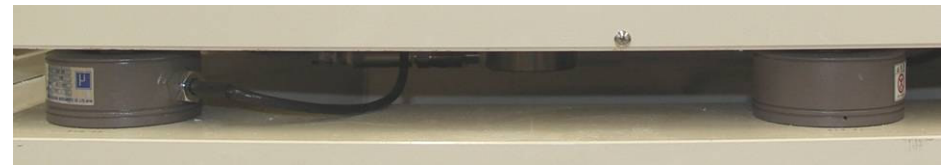
Outline

- 1. Objectives**
- 2. Polishing Apparatus**
- 3. Abrasive Particle Size Studies**
- 4. STI Patterned Wafers Studies**
- 5. Summary**

Objectives

- Investigate the effect of abrasive particle size (in ceria-based slurries) on:
 - Shear force (F_y)
 - Coefficient of friction (COF)
 - Removal rate (RR)
- Determine whether spectral analysis (based on raw force data) can generate unique spectral fingerprints before, during and after transition to Si_3N_4 during polishing of STI patterned wafers

The Araca APD – 500 Polisher & Tribometer



Abrasive Particle Size Studies

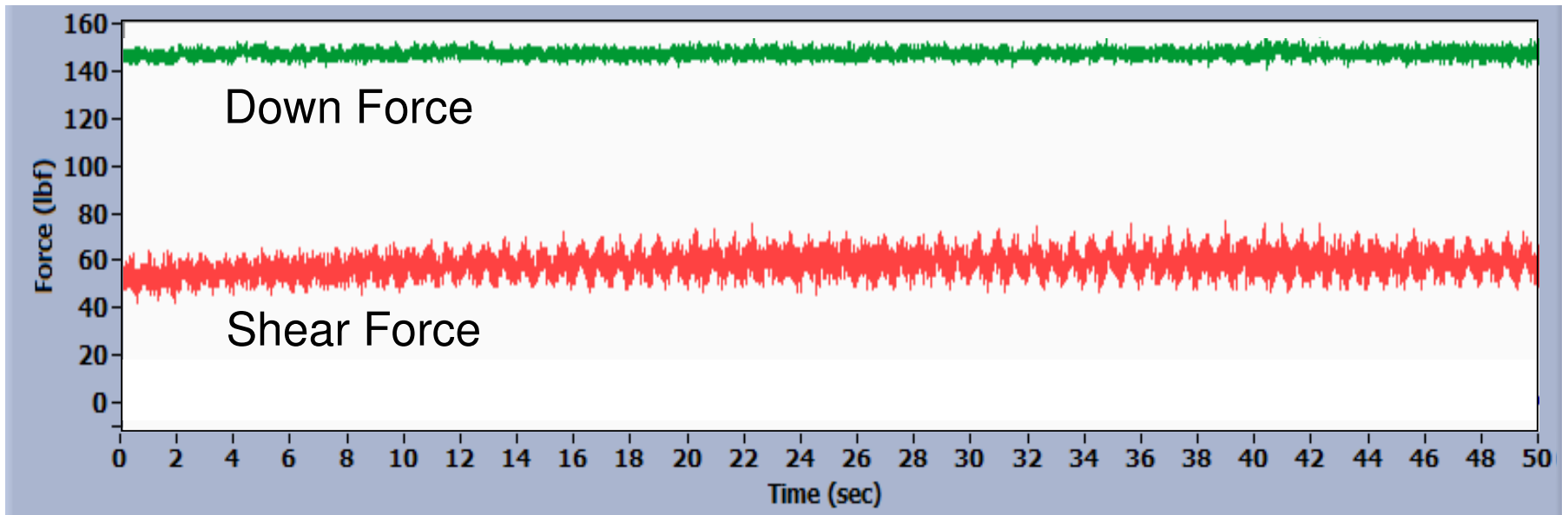
Experimental Conditions

- **Diamond disc conditioner: 107 mm MMC TRD 100 grit**
- **Conditioning force: 5.8 lb_f (25.8 N)**
- **Conditioning : *In-situ* at 30 RPM disc speed & 10 per minute sweep frequency**
- **Wafers: 200 mm blanket PETEOS**
- **Wafer pressure : 3 PSI (20.7 KPa)**
- **Sliding velocity : 93 RPM for platen and 87 RPM for wafer carrier**
- **Slurry flow rate : 200 cc/min**
- **Slurry: Four different ceria-based slurries**

	I	II	III	IV
D ₅₀ (nm)	160	180	190	200
D ₉₉ (nm)	400	500	700	1000

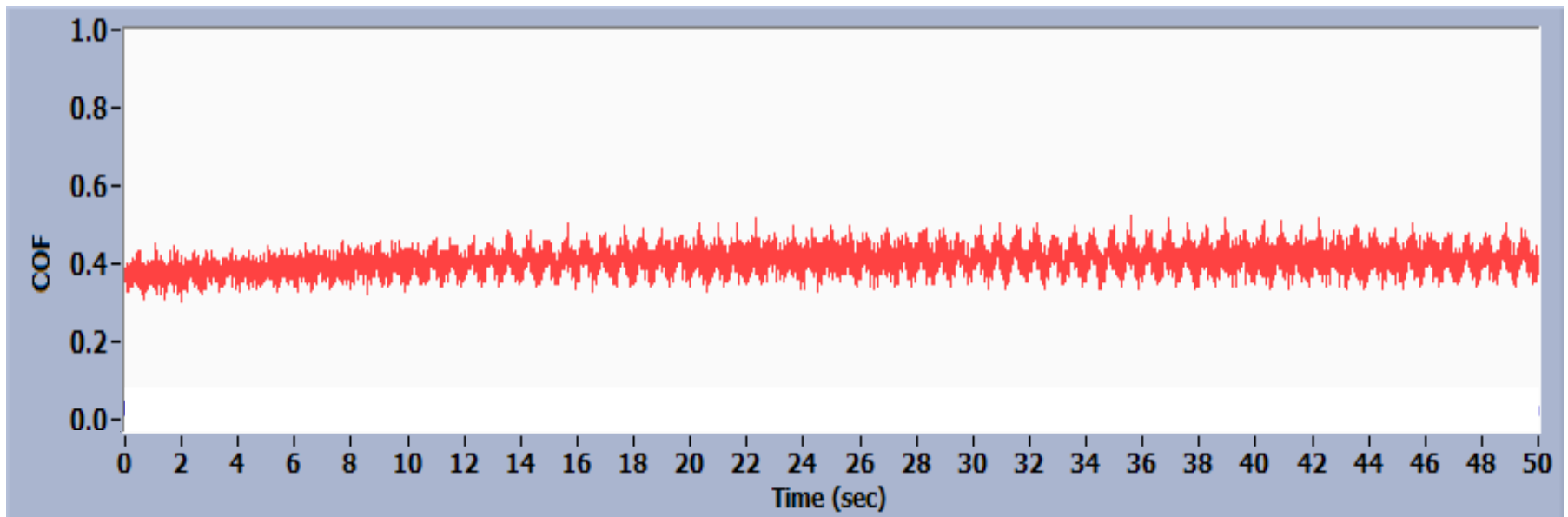
- **Pad : 500 mm RHEM IC1000 A2 K groove**
- **Polishing time: 60 seconds**

Raw Force Measurement



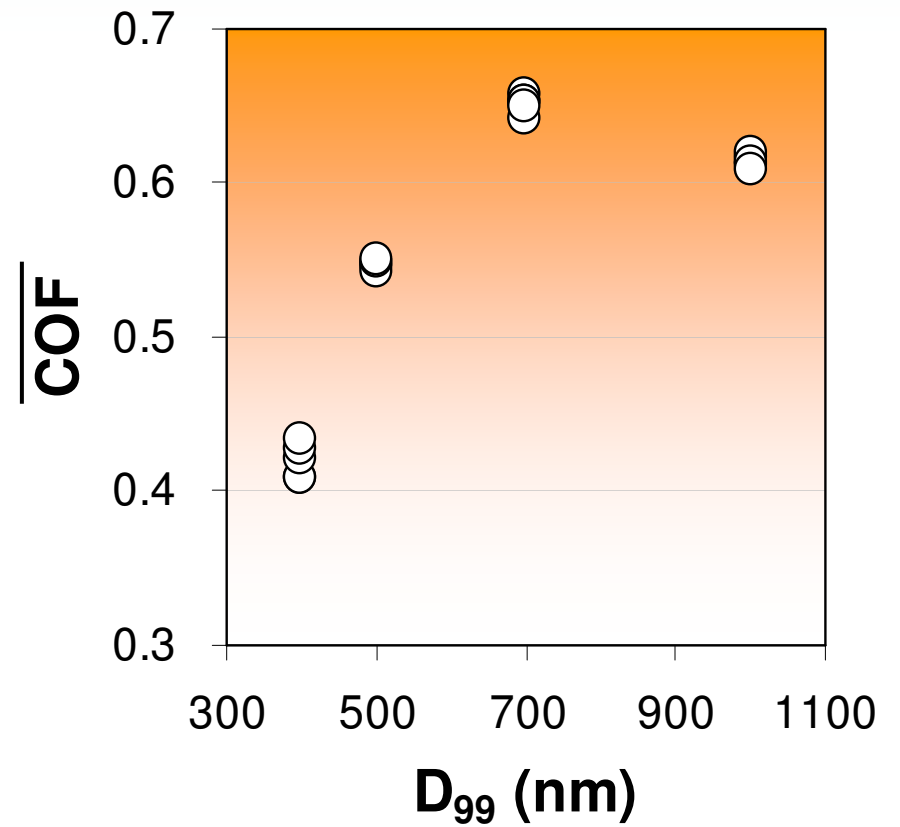
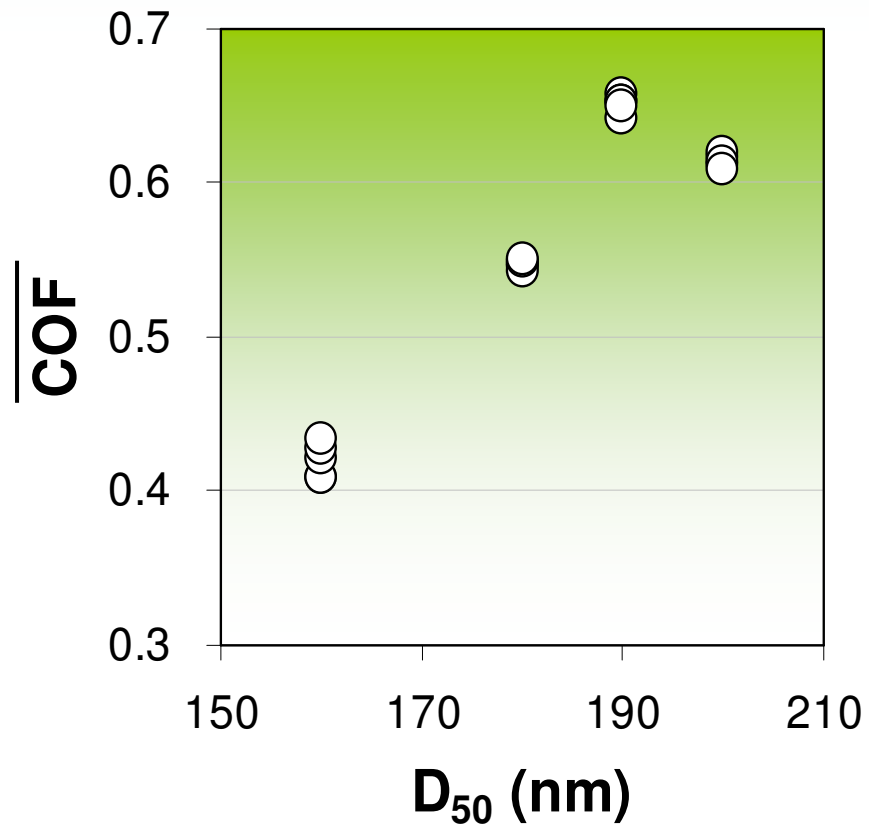
$$\text{COF}_i = \frac{\text{Shear Force}_i}{\text{Down Force}_i}$$

Coefficient of Friction (COF)

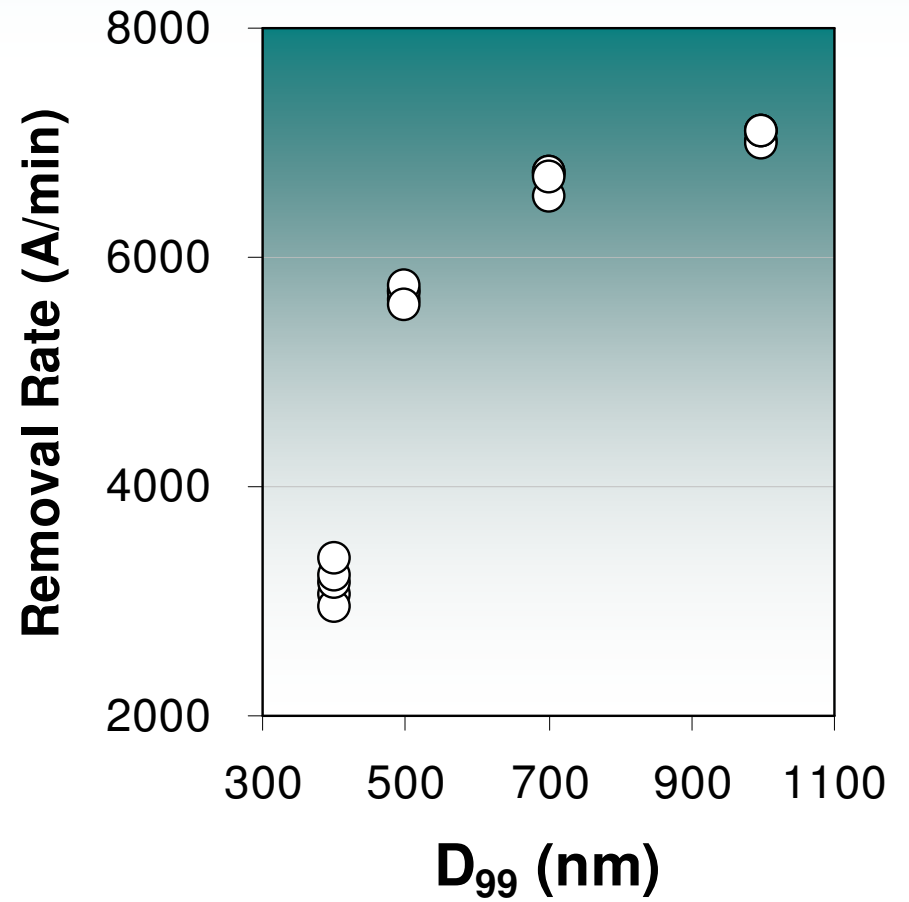
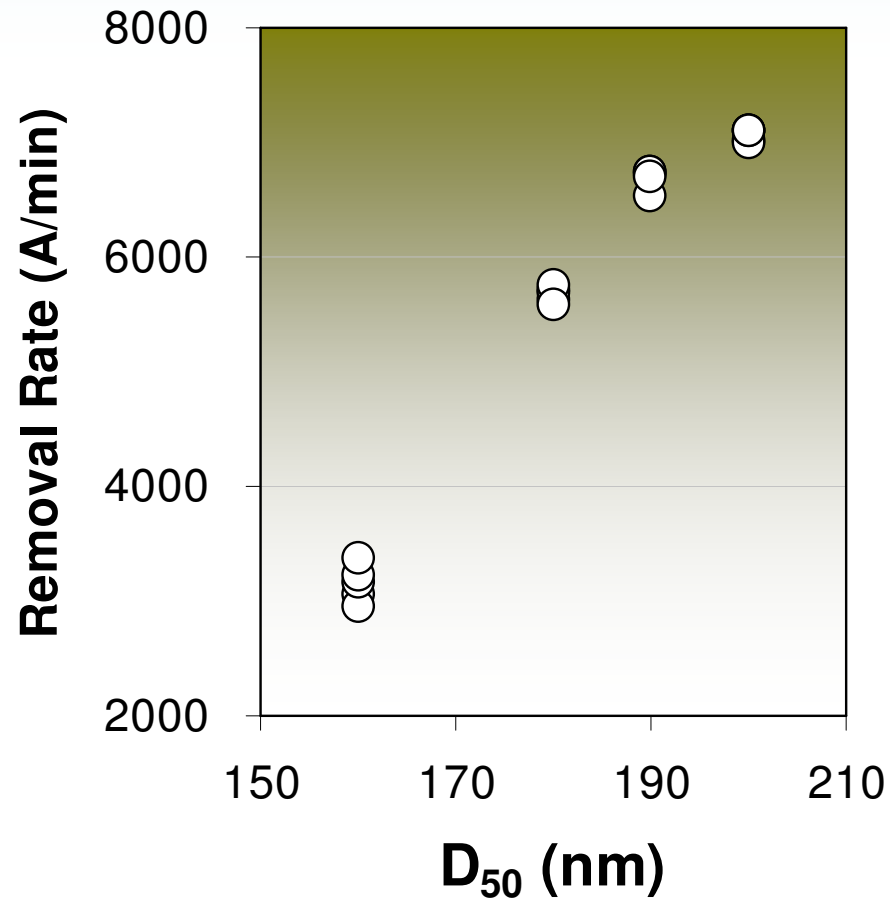


$$\overline{\text{COF}} = \frac{\sum_i \text{COF}_i}{i}$$

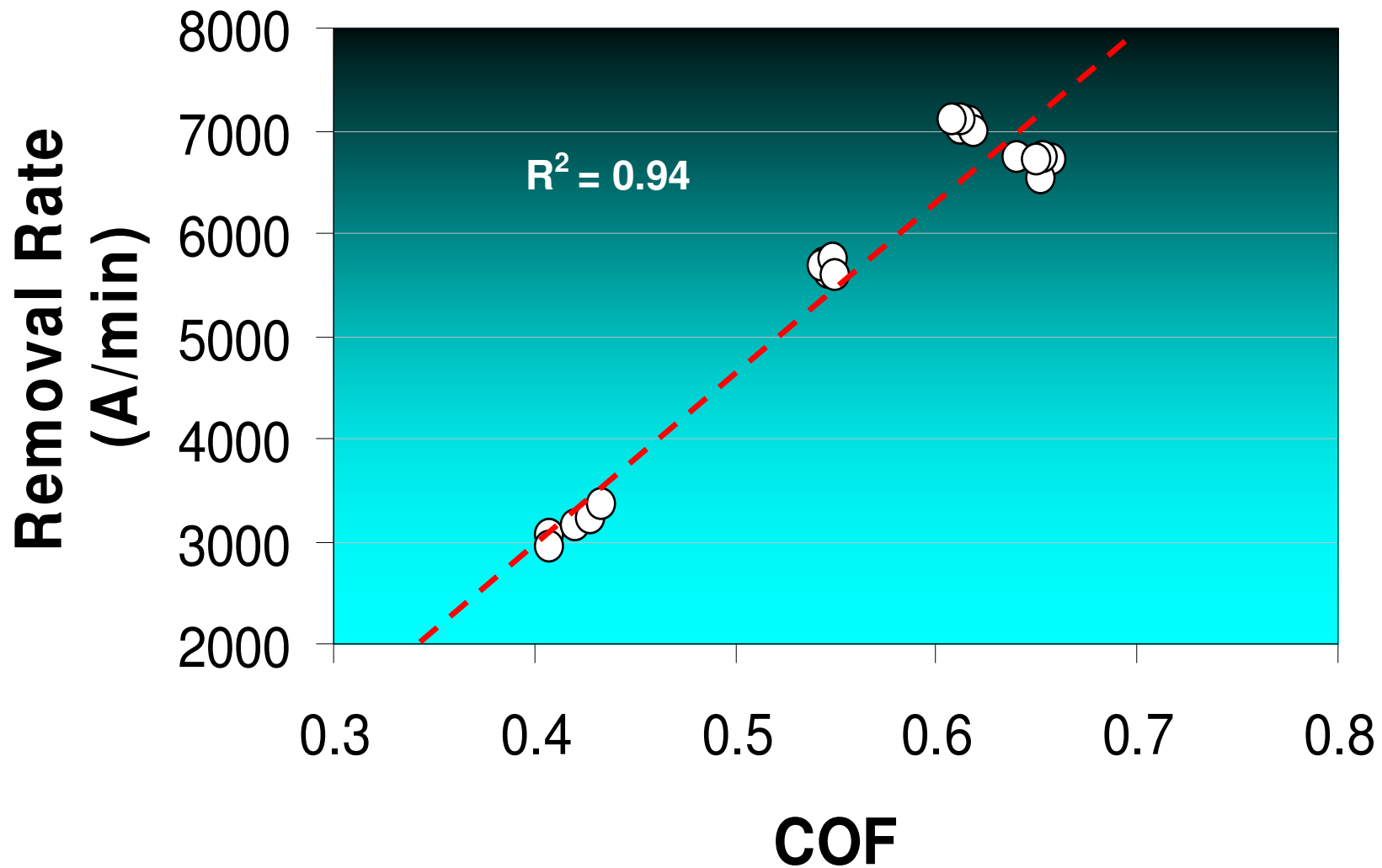
COF Results (n = 5)



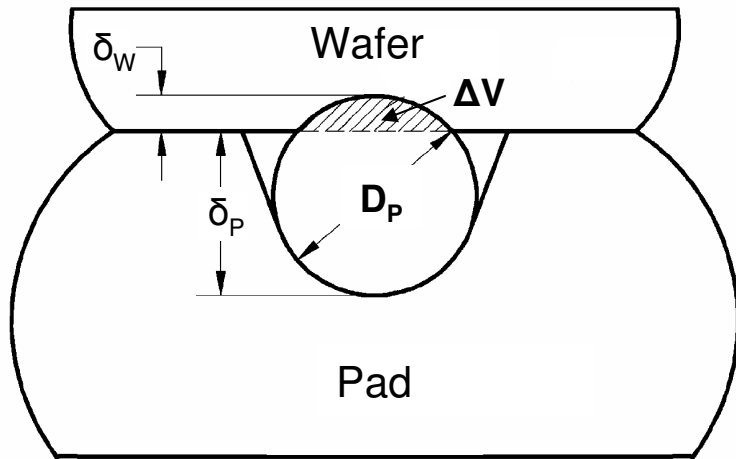
Removal Rate Results (n = 5)



Correlating RR to COF for all 4 Slurries



Modeling the Effect of Abrasive Particle Size



$$F_{cp} = F_{cw}$$

$$\frac{4}{3} E_{cp} \left(\frac{D_p}{2} \right)^{1/2} \delta_p^{3/2} = H_w \pi D_p \delta_w$$

$$\delta_w + \delta_p = D_p$$

$$\delta_w^3 + \left(\frac{9 \pi^2 H_w^2}{8 E_{cp}^2} - 3 \right) D_p \delta_w^2 + 3 D_p^2 \delta_w - D_p^3 = 0$$

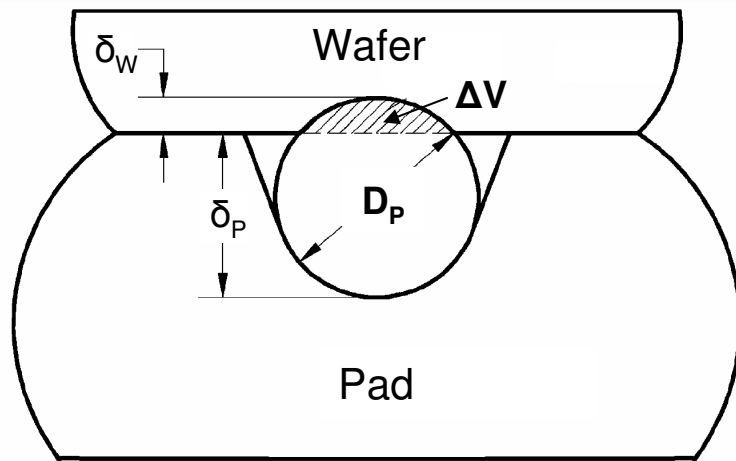
$$H_w = 8.3 \times 10^9 \text{ Pa}$$

$$E_{cp} \approx E_{sp} = 3.33 \times 10^7 \text{ Pa}$$

K. Johnson, Contact Mechanics (1985)

Y. Zhao and L. Chang, Wear 252: 220-226 (2002)

Modeling the Effect of Abrasive Particle Size



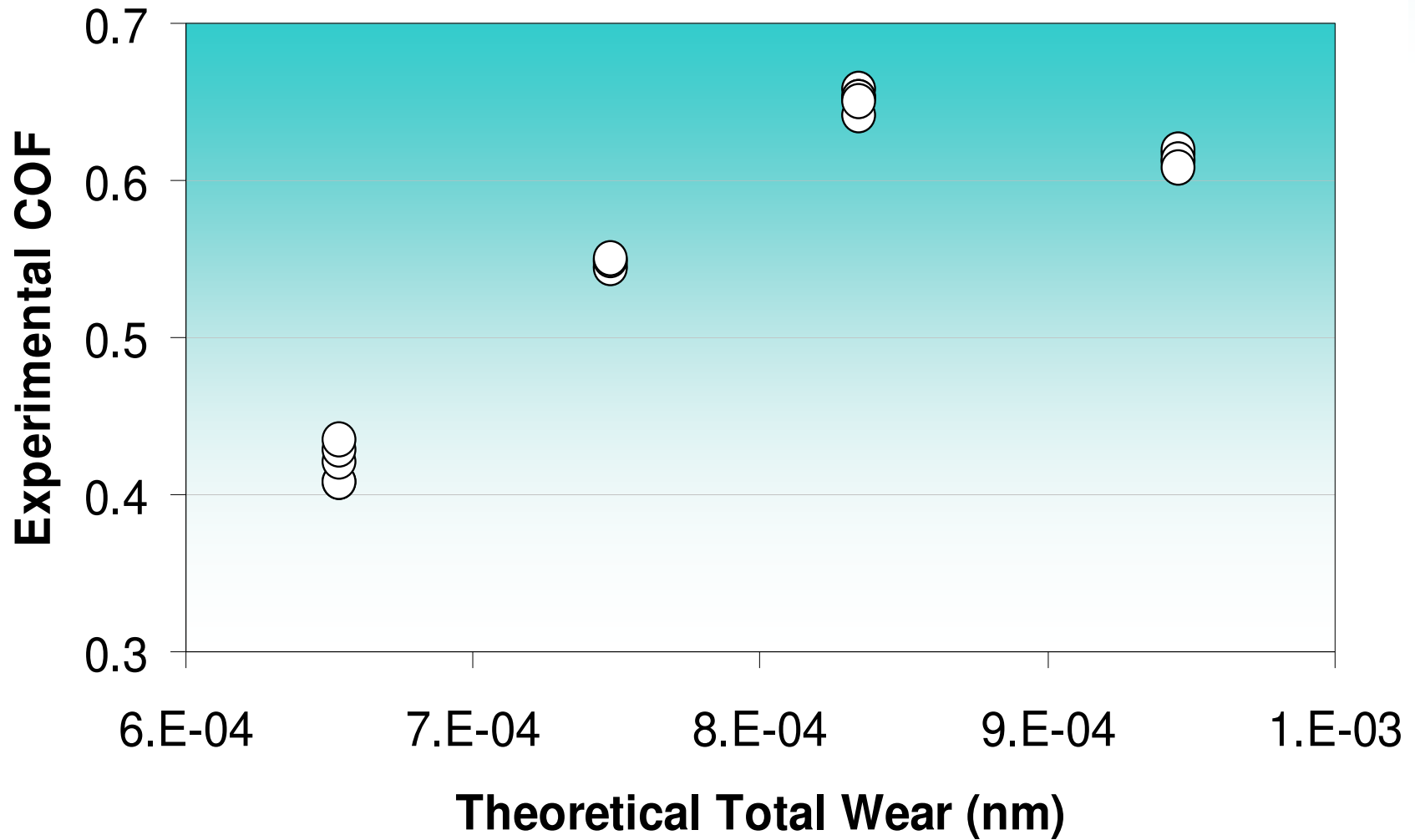
$$\Delta V = \pi \left(\frac{D_p^2 \delta_w}{4} + \frac{(D_p - \delta_w)^3}{3} - \frac{D_p^3}{6} \right)$$

$$N_a = A_t \left(\frac{6 X_v}{\pi D_p^3} \right)^{2/3} \quad N_{ao} \approx \left(\frac{6 X_v}{\pi D_p^3} \right)^{2/3}$$

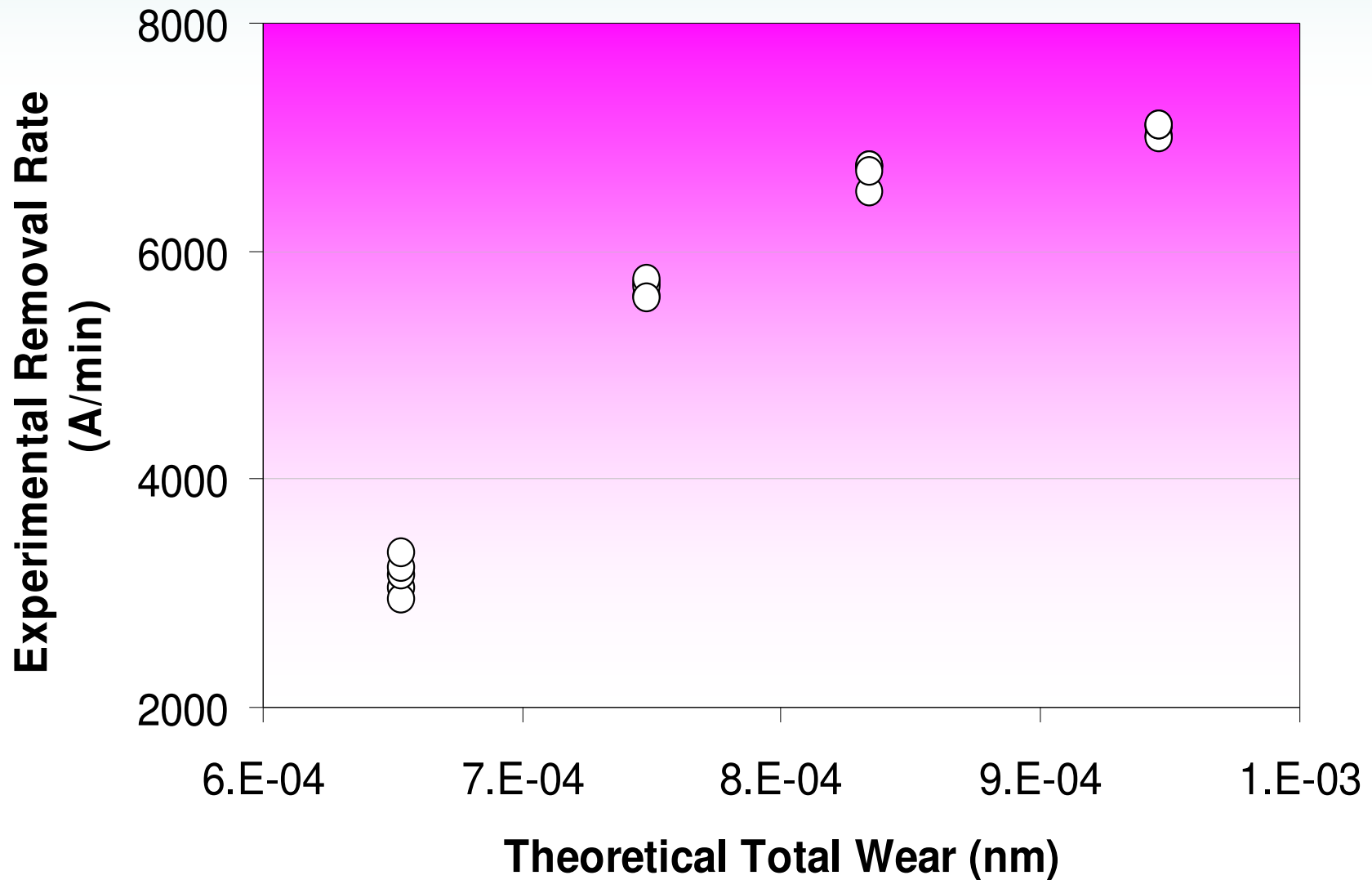
$$\text{Wear} \approx \Delta V \cdot N_{ao}$$

	D_{50}					D_{99}					Total Wear (nm)
	D_p (nm)	δ_w (nm)	ΔV (nm ³)	N_{ao} (nm ⁻²)	Wear (nm)	D_p (nm)	δ_w (nm)	ΔV (nm ³)	N_{ao} (nm ⁻²)	Wear (nm)	
Slurry 1	160	0.19	9.3	5.97E-5	5.51E-4	400	0.48	145.1	4.47E-7	1.03E-4	6.19E-4
Slurry 2	180	0.22	13.2	4.72E-5	6.20E-4	500	0.60	283.4	2.86E-7	1.29E-4	7.05E-4
Slurry 3	190	0.23	15.6	4.24E-5	6.54E-4	700	0.84	777.6	1.46E-7	1.80E-4	7.72E-4
Slurry 4	200	0.24	18.1	3.82E-5	6.89E-4	1000	1.20	2267.2	7.14E-8	2.57E-4	8.55E-4

Correlating COF to Theoretical Extent of Wear



Correlating Experimental RR to Theoretical Extent of Wear

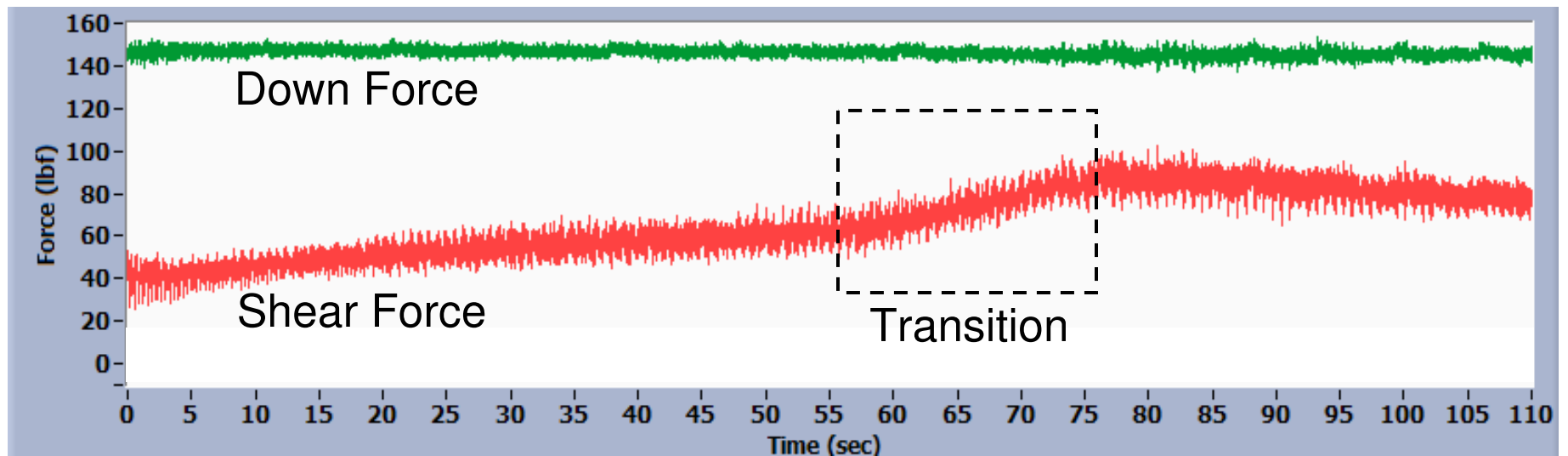
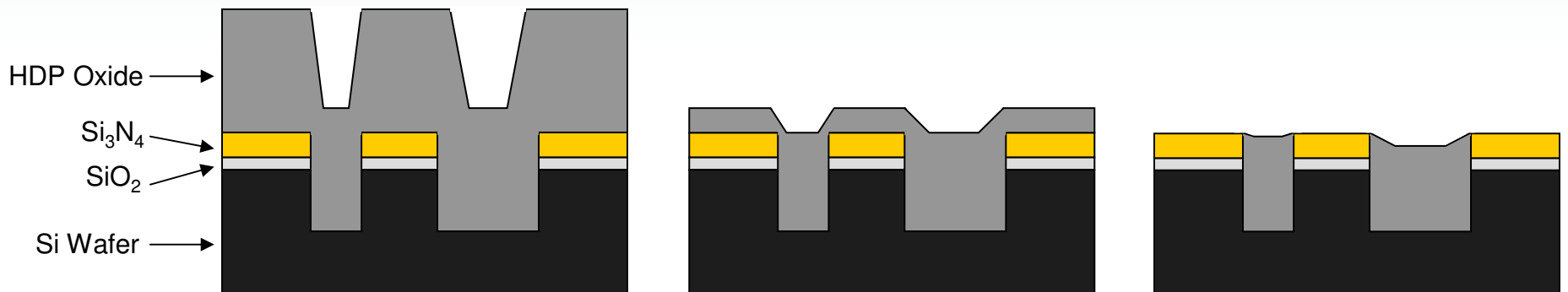


STI Patterned Wafer Studies

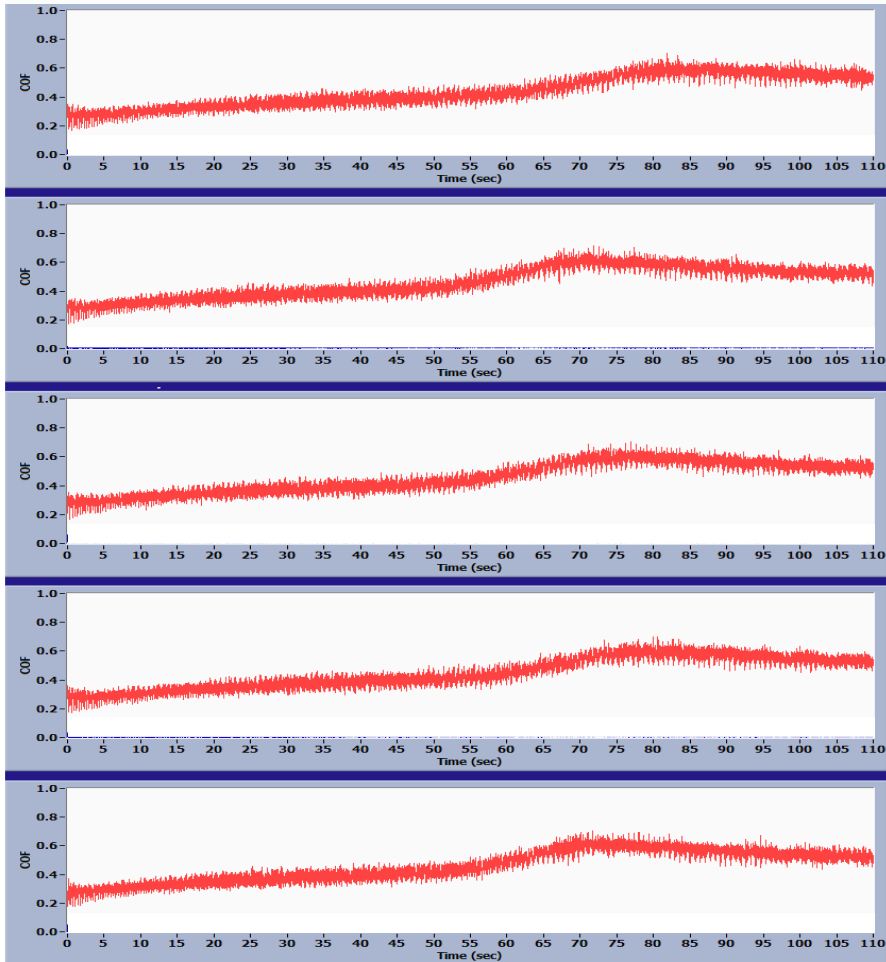
Experimental Conditions

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- **Conditioning force: 5.8 lb_f (25.8 N)**
- **Conditioning : *In-situ* at 30 RPM disc speed & 10 per minute sweep frequency**
- **Wafers: 200 mm SKW STI patterned wafers**
- **Wafer pressure : 3 PSI (20.7 KPa)**
- **Sliding velocity : 93 RPM for platen and 87 RPM for wafer carrier**
- **Slurry flow rate : 200 cc/min**
- **Slurry: Ceria-based slurry with D₅₀ of 190 nm (D₉₉ of 700 nm)**
- **Pad : 500 RHEM IC1000 A2 K groove**
- **Polishing time: 110 seconds**

Shear Force Measured on STI Patterned Wafers



COF Transients for 5 Wafers



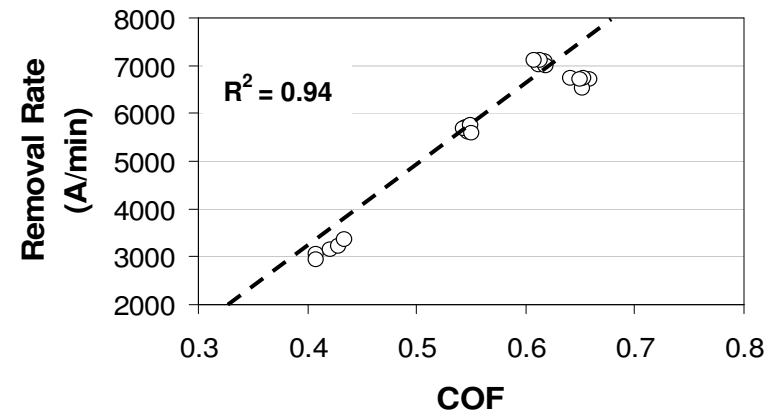
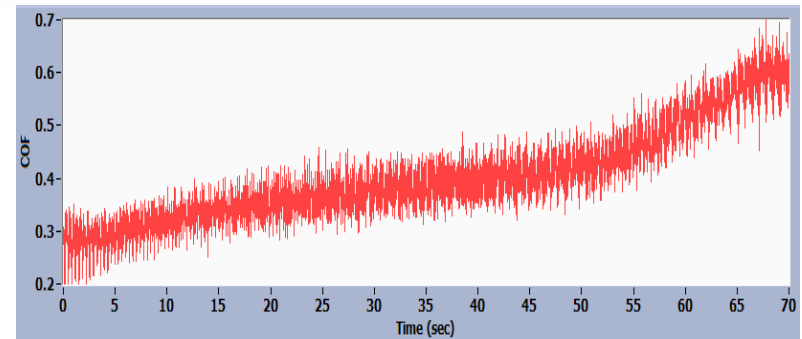
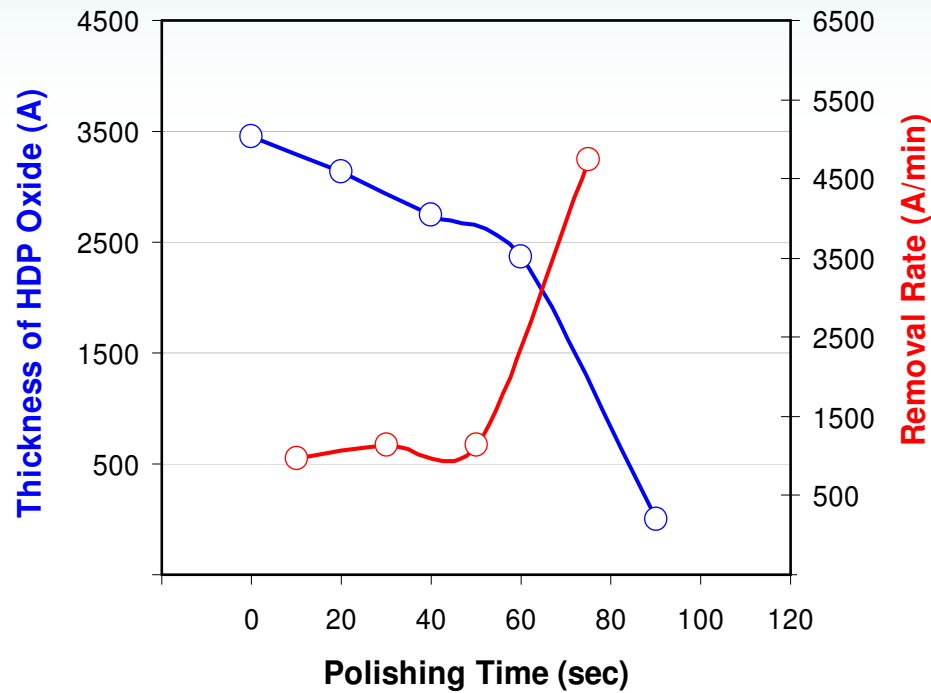
Polish Time

	Transition Start (s)	Transition End (s)
Average	56.4	71.4
SD	3.4	4.5
RSD	6.1%	6.3%

Coefficient of Friction

	Before Transition	During Transition	After Transition
Average	0.361	0.510	0.566
SD	0.004	0.006	0.008
RSD	0.1%	0.3%	0.5%

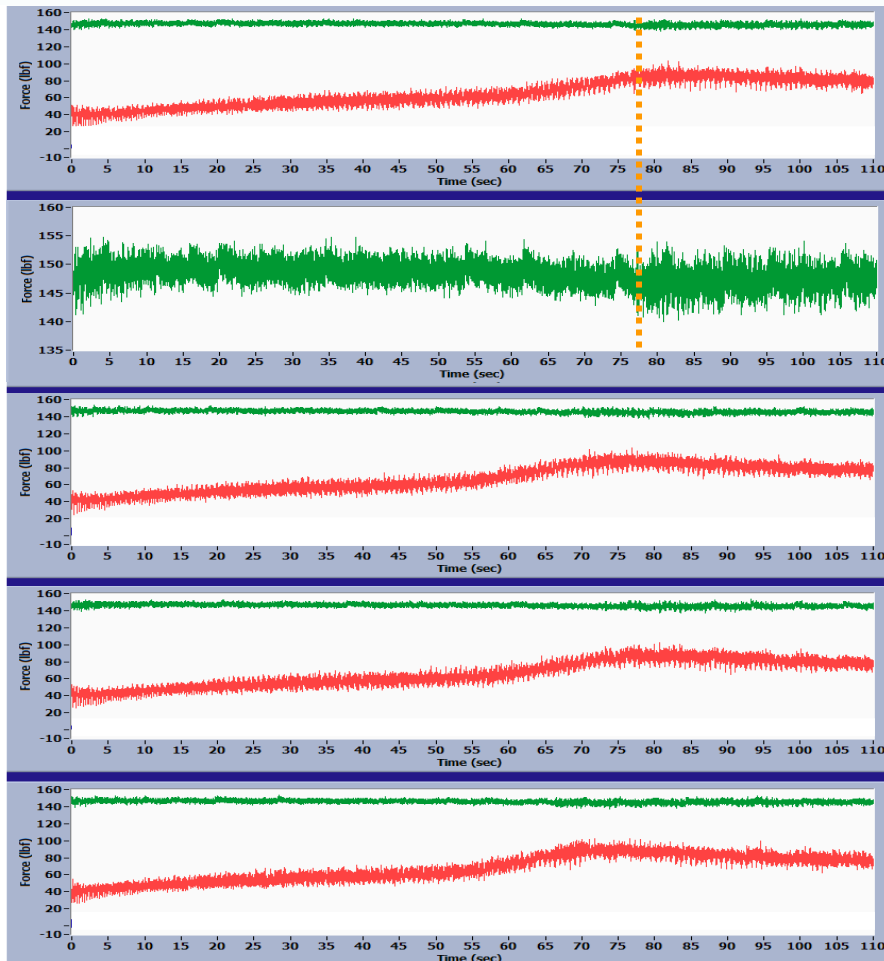
Comparing to Data in the Literature



- STI patterned wafer
- Ceria slurry
- Mean particle size = 312 nm
- IC1000 pad

D. Lim et al., Surface & Coatings Technology **200**:1751-1754 (2005)

Force Transients for 5 Wafers



Polish Time

	Transition Start (s)	Transition End (s)
Average	56.4	71.4
SD	3.4	4.5
RSD	6.1%	6.3%

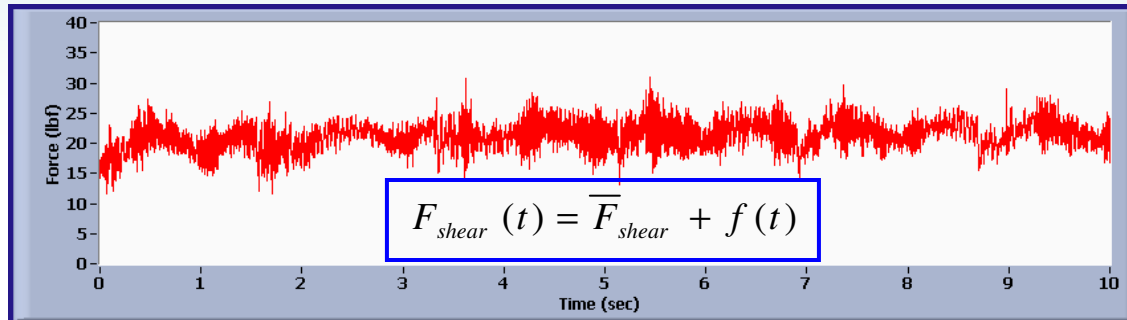
Variance of Shear Force (σ^2)

	Before Transition (lb_f^2)	During Transition (lb_f^2)	After Transition (lb_f^2)
Average	58.7	57.8	33.6
SD	2.8	7.7	9.2
RSD	4.7%	13.3%	27.4%

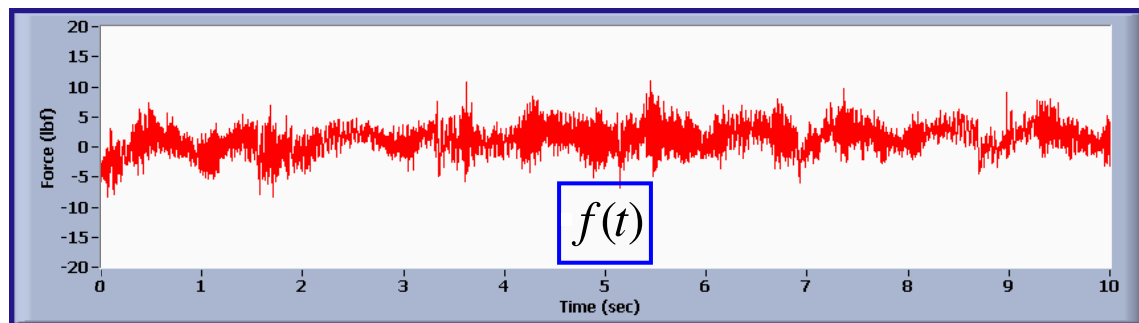
Variance of Down Force (σ^2)

	Before Transition (lb_f^2)	During Transition (lb_f^2)	After Transition (lb_f^2)
Average	2.3	2.2	3.4
SD	0.03	0.22	0.19
RSD	1.3%	10%	5.5%

Spectral Analysis of Raw Force Data

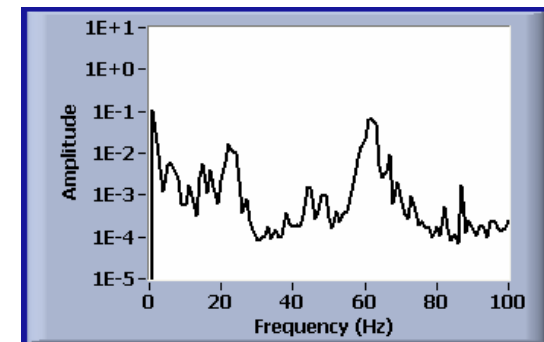


Subtracted by \bar{F}_{shear}



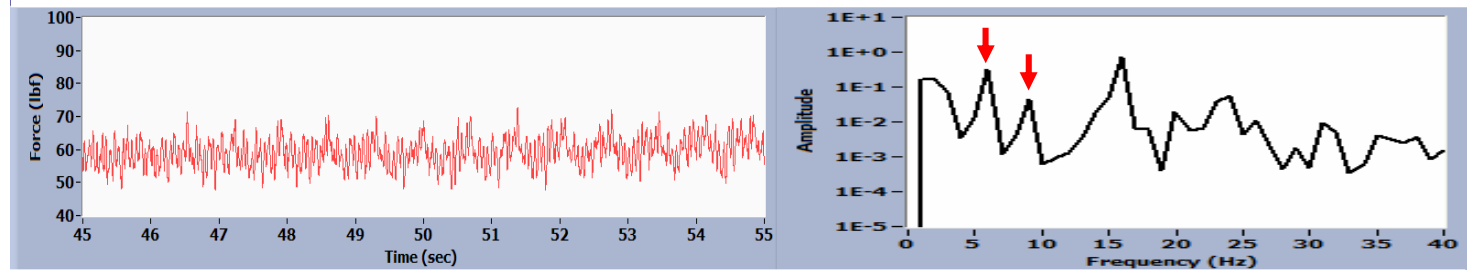
Time domain \rightarrow Frequency domain

Fast Fourier Transform

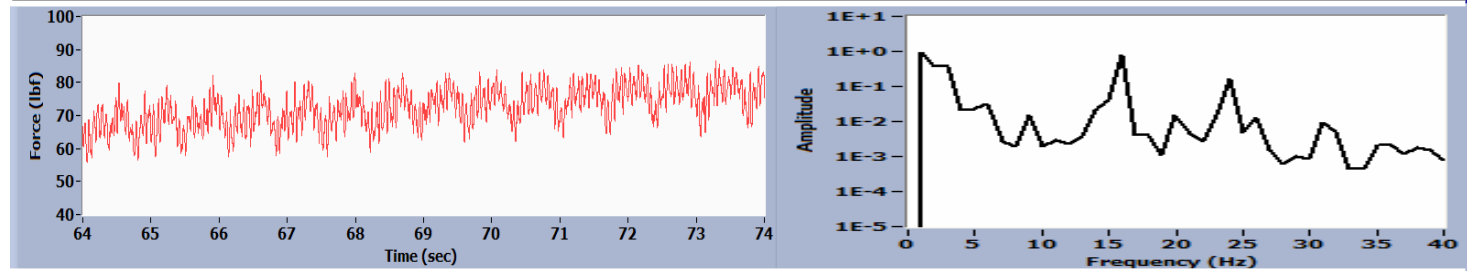


Spectral Analysis of Shear Force for STI Patterned Wafer No. 1

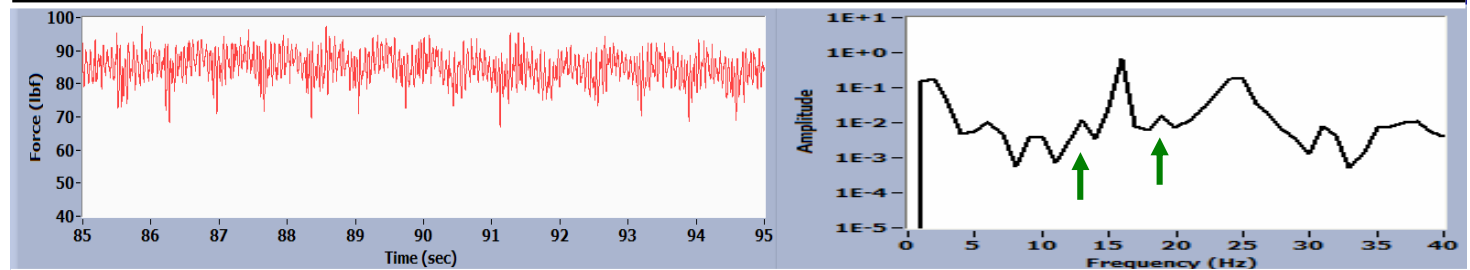
Before Transition



During Transition

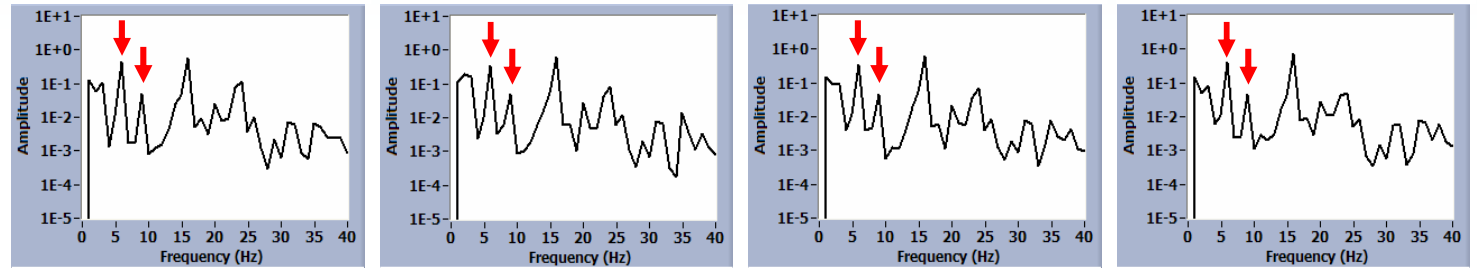


After Transition

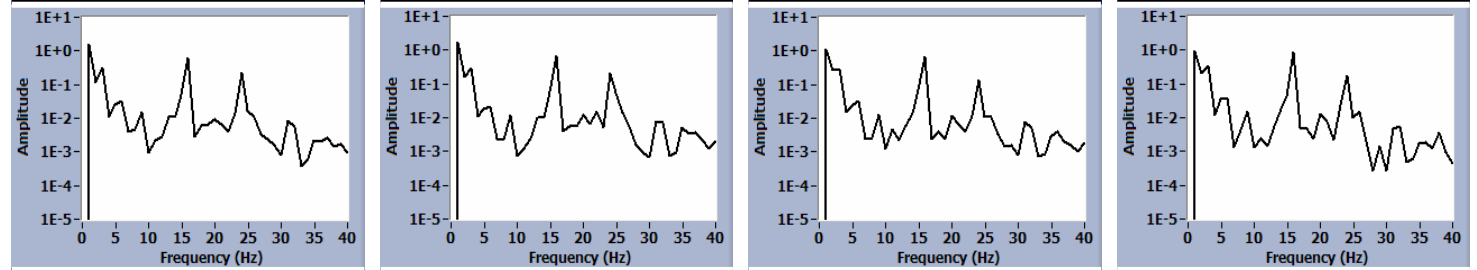


Spectral Analysis of Shear Force for Wafer Nos. 2 – 5

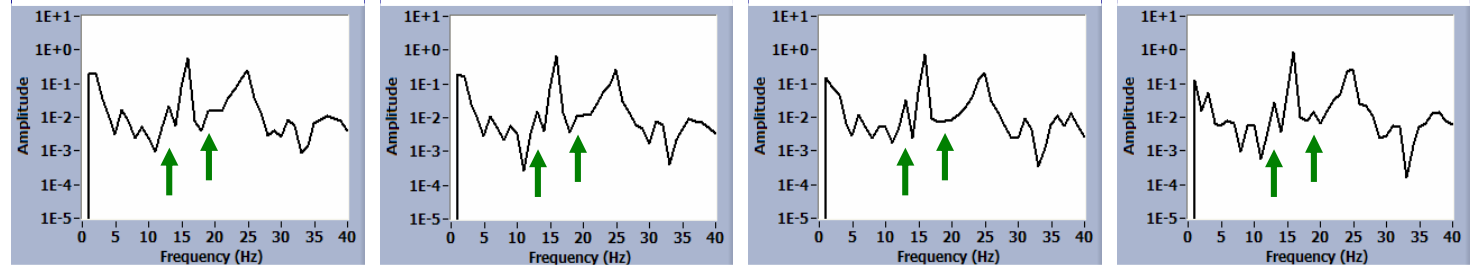
Before Transition



During Transition

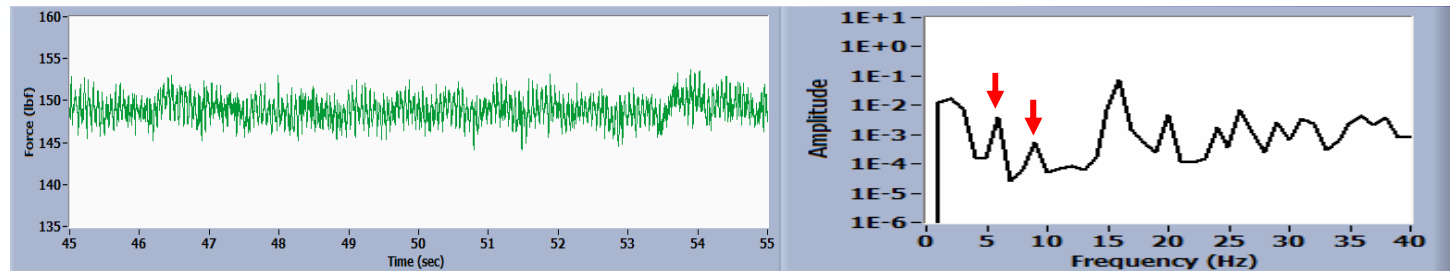


After Transition

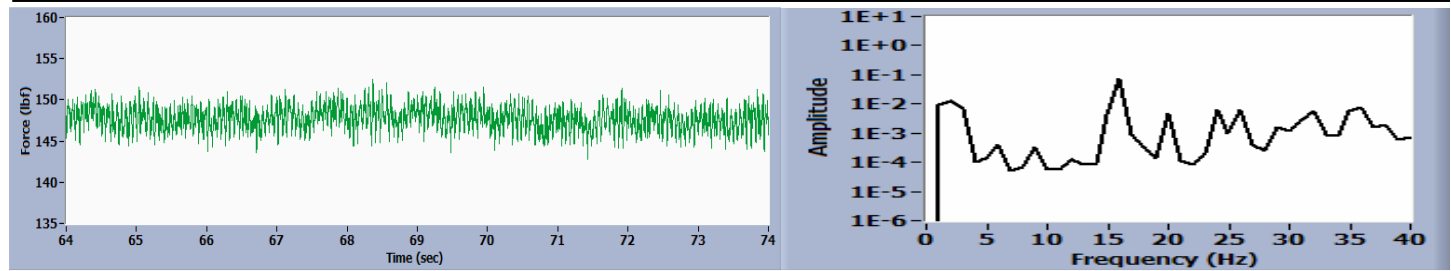


Spectral Analysis of Down Force for STI Patterned Wafer No. 1

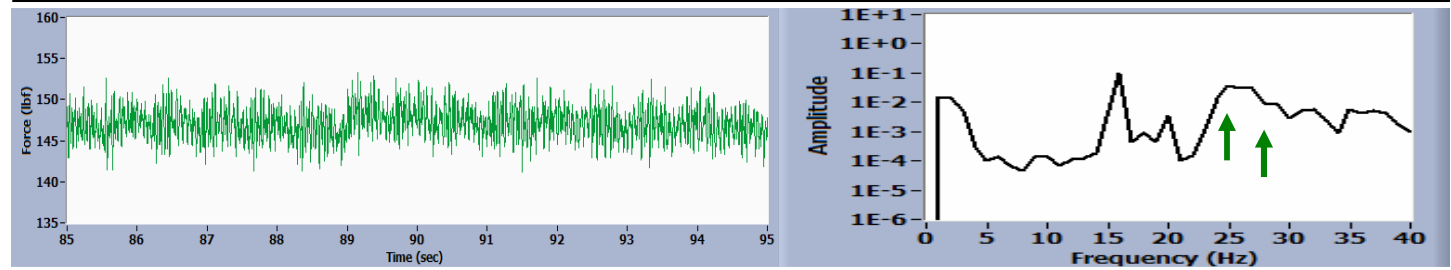
Before Transition



During Transition

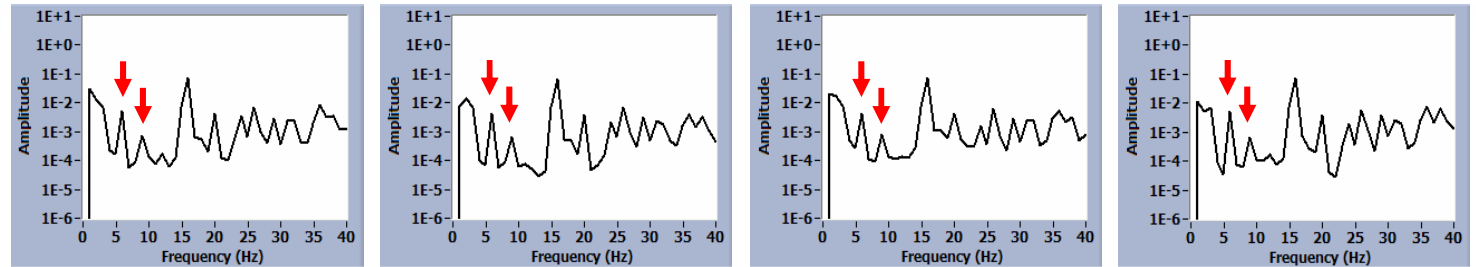


After Transition

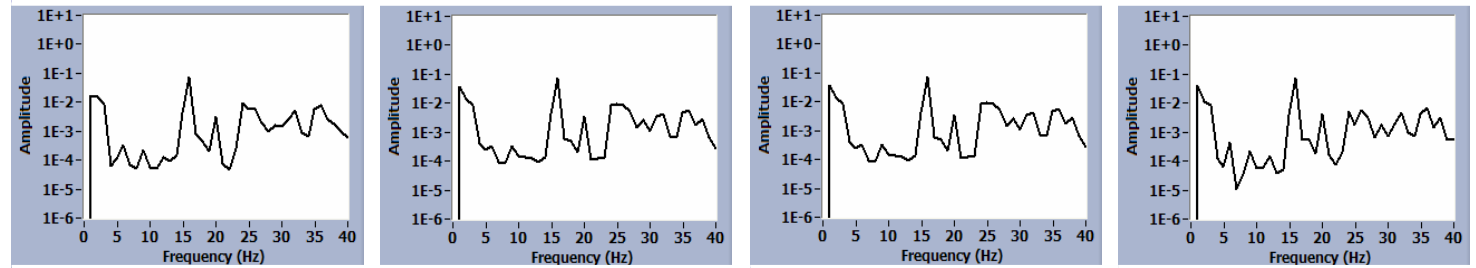


Spectral Analysis of Down Force for Wafer Nos. 2 – 5

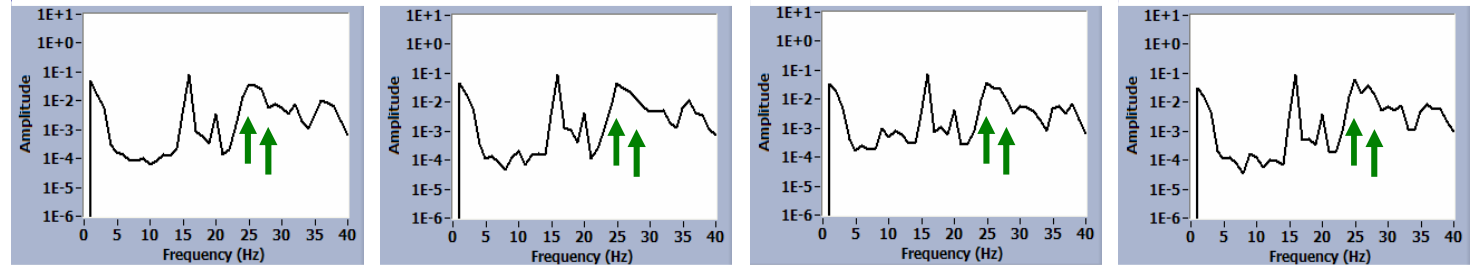
Before Transition



During Transition



After Transition



Summary

- **During blanket PETEOS CMP, larger cerium oxide particles induce higher COFs which also lead to higher RRs**
- **At higher RRs, correlation between theoretical wear and RR becomes non-linear. This is possibly due to a shift from mechanically-limited process (i.e. the model's assumption) to a chemically-limited process (due to nature of ceria particles)**
- **Transition to silicon nitride is also detected through:**
 - Lower variance of shear force
 - Higher variance of down force
 - Higher COF
- **Force spectral analysis shows unique spectral fingerprints capable of systematically distinguishing vibrational events before, during and after transition to Si_3N_4 during STI CMP**