Effect of Pad Conditioning Methods on Wafer-Slurry-Pad Coefficient of Friction

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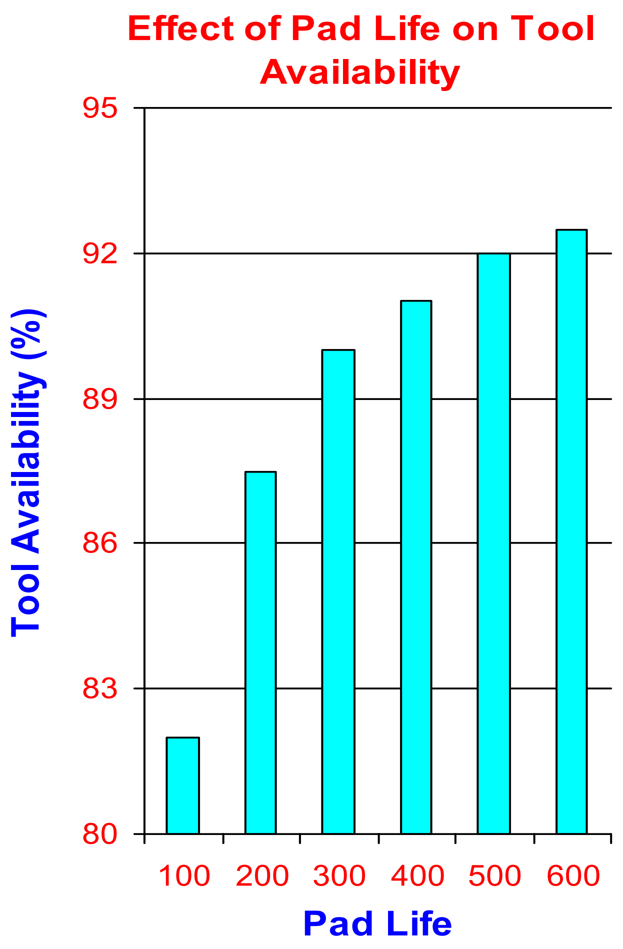
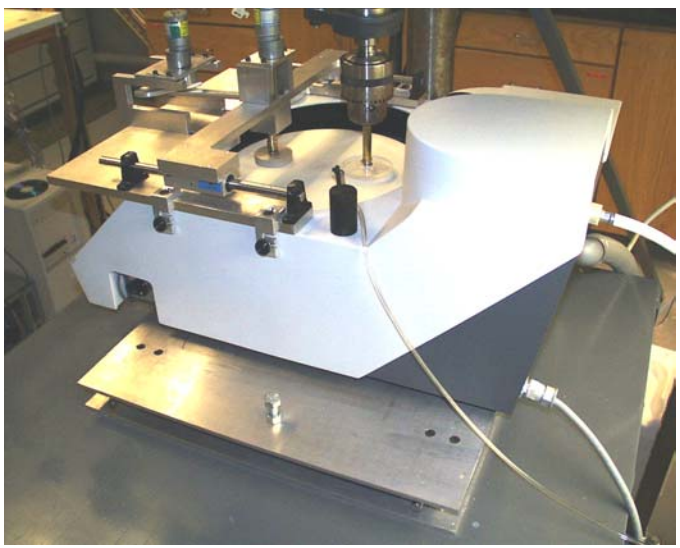
Motivation

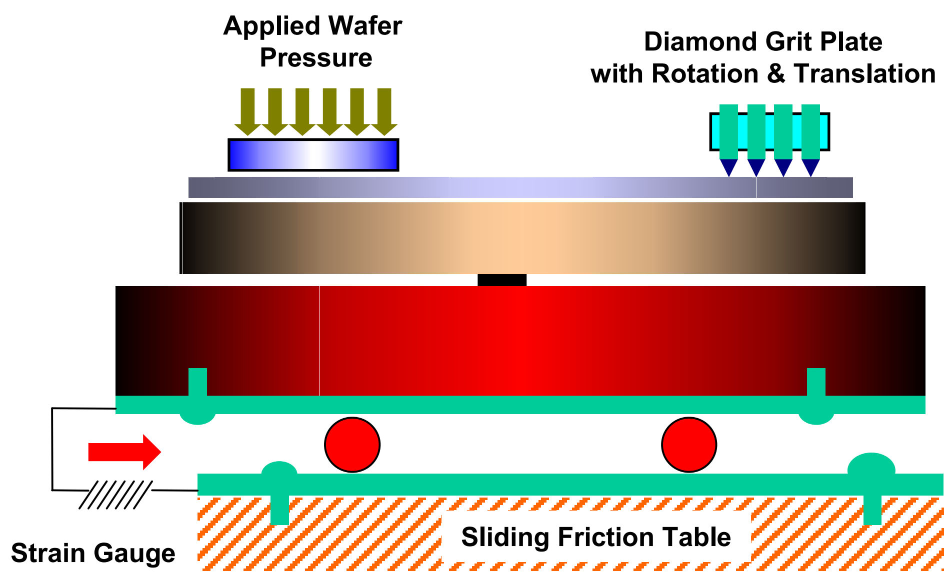
- Characterization, fundamental understanding, and control of the magnitude of shear forces in the pad-slurry-wafer region is an integral element in developing optimal planarization processes
- Adoption of improved pad conditioning schemes will be required to impart desired shear forces on the wafer during CMP and modulate pad life



Apparatus

Parameter	Scaling Factor	Speedfam-IPEC 472	Rotopol-35
Down Pressure	1	4 psi	4 psi
Platen Speed	Reynolds Number	Relative pad-wafer velocity of 0.5 m per second (~ 30 rpm)	Relative pad-wafer velocity of 0.5 m per second (~ 54 rpm)
Platen Diameter / Wafer Diameter	D_{platen} / D_{wafer}	51 cm / 15 cm	31 cm / **9 cm**
Slurry Flow Rate	Platen Surface Area	125 cc per minute	45 cc per minute

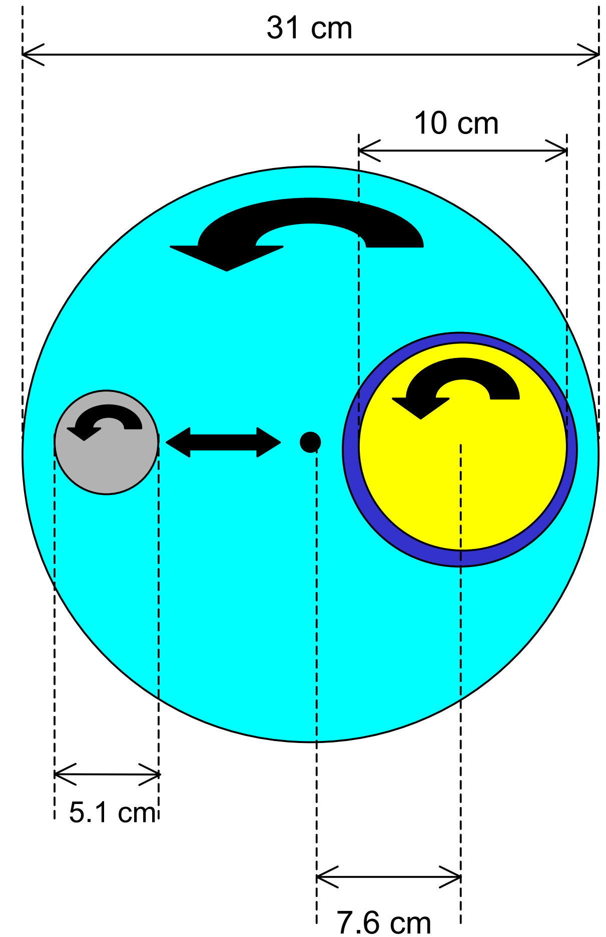




Apparatus

Experimental Procedure

- Pad
  - Rodel IC-1000 or Freudenberg FX-9 polyurethane
- Break-In
  - 100 grit diamond disk
  - 30 min with Fujimi PL-4217 (same dilution as the experiment) at 30 rpm disk speed and 30 per min sweep frequency
- Polisher Settings
  - 80 rpm platen speed… 0.62 m/s
  - 3 PSI wafer down force
- Wafers
  - Bare Silicon
- Slurry Injector position
  - Center of pad

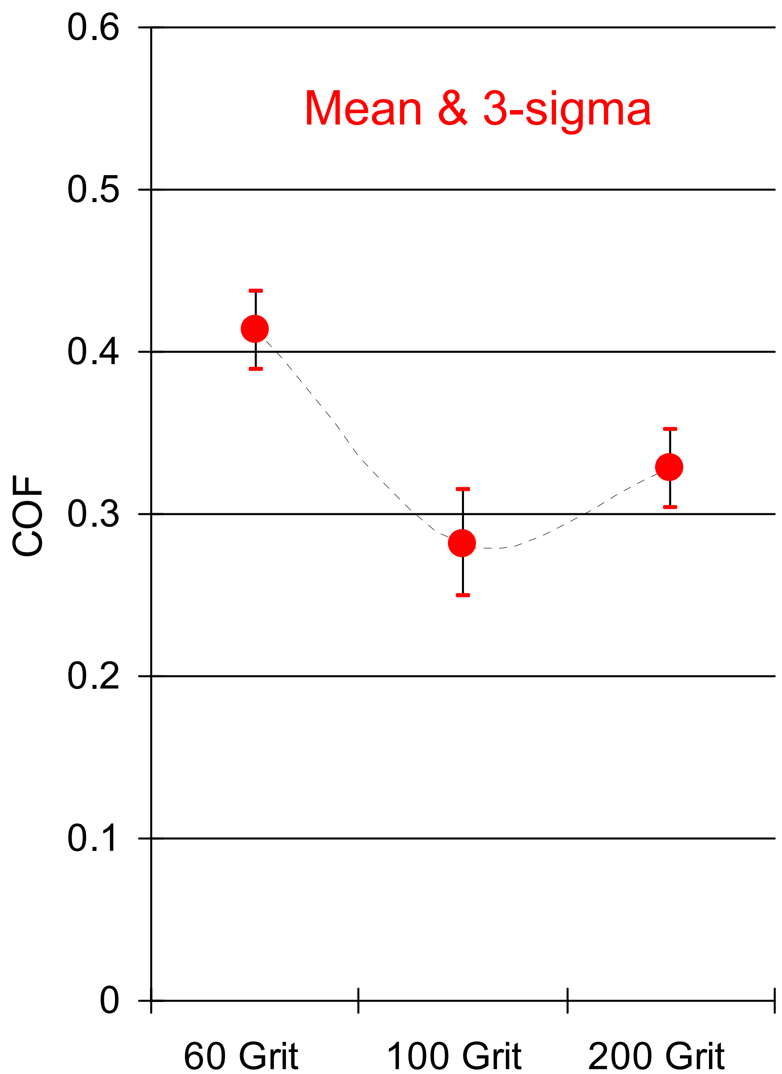


Experimental Procedure - Phase I

What is the effect of conditioner kinematics and diamond grit size on COF?

- Phase I
  - Rodel IC-1000 pad
  - Initial pad conditioning and break-in
  - Slurry … Fujimi PL-4217 (fumed silica) at 12.5% solids
  - Polisher conditions:
    - Relative wafer-pad velocity … 0.62 meters per sec
    - Wafer pressure … 3 PSI
    - Slurry flow rate … 35 cc per minute
  - Conditioning parameters:
    - Diamond disk … 60, 100, & 200 grit (perforated disk)
    - Disk speed … 30, 50, & 70 rpm
    - Disk sweep frequency … 10, 20, & 30 oscillations per minute
  - Condition pad ex-situ for 8 minutes and record COF data in-situ for 2 minutes

Results - Phase I

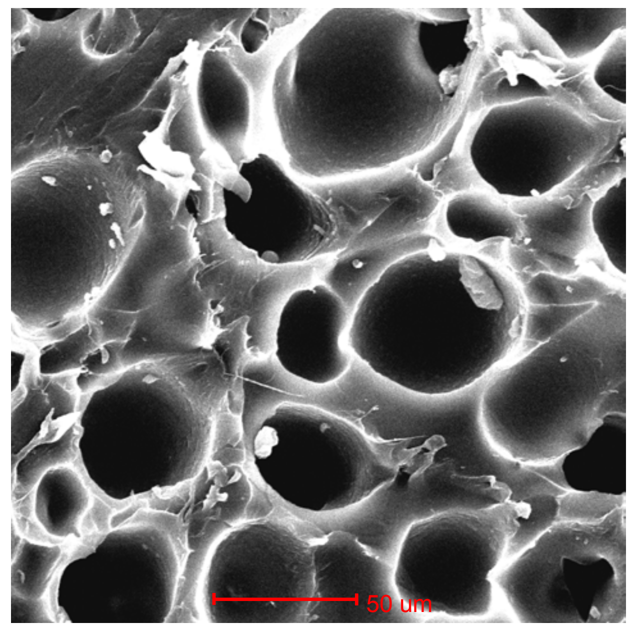


- As a first approximation:
  - No relationship was found between disk sweep frequency and COF
  - No relationship was found between disk rotational speed and COF
- Diamond grit size seems to be a critical parameter and warrants further study

Diamond Particle Size Compared to Characteristics of a Pad

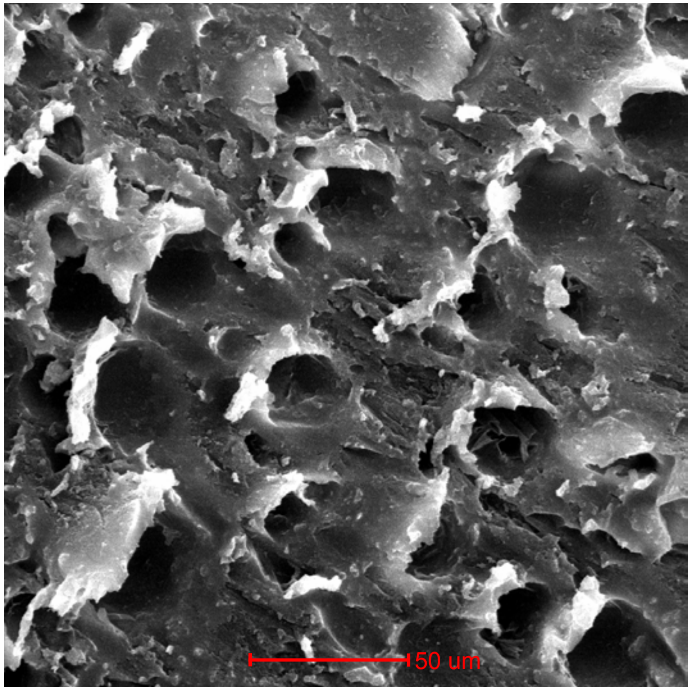
Diamond Mesh	Length (microns)
400	38.1
325	43.2
270	53.3
230	61.0
200	68.0
170	88.9
140	104.1
120	124.5
100	149.9
80	177.8
60	248.9

- Characteristics of a Pad
  - Pore diameter ~ 50 microns
  - 10 to 30 microns between asperities

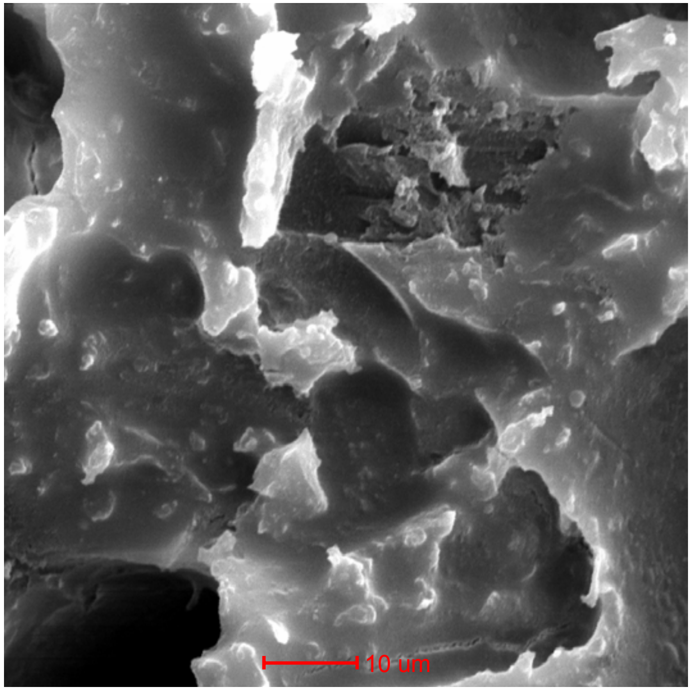


SEM Image : Rodel IC-1000 polyurethane unused pad

Pad Degradation from a 100 Grit Diamond Conditioner



Rodel IC-1000
Magnification 500X



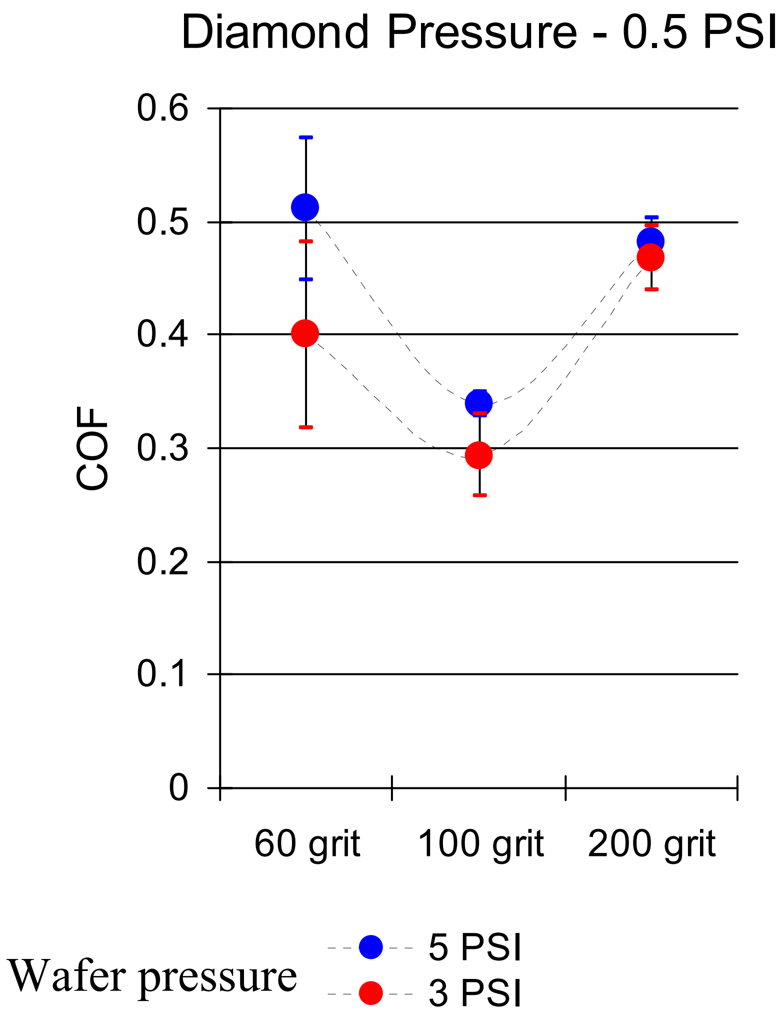
Freudenberg FX-9
Magnification 1500X

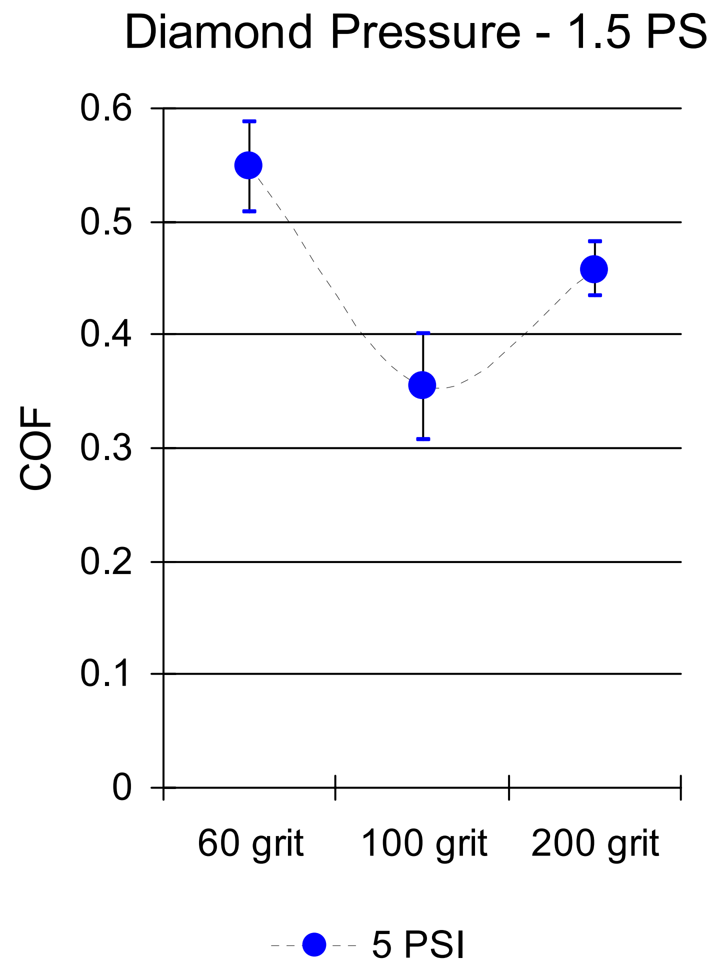
Experimental Procedure - Phase II

What are the effect of diamond disk pressure and wafer pressure on COF?

- Phase II
  - Freudenberg FX-9 pad
  - Initial pad conditioning and break-in
  - Slurry … Fujimi PL-4217 (fumed silica) at 12.5% solids
  - Polisher conditions:
    - Relative wafer-pad velocity … 0.62 meters per sec
    - Wafer pressure … 3 & 5 PSI
    - Slurry flow rate … 35 cc per minute
  - Conditioning parameters:
    - Disk speed … 50 rpm
    - Disk sweep frequency … 20 per min
    - Diamond disk … 60, 100 & 200 grit
    - Conditioning disk down force… 0.5 &1.5 PSI
  - Condition pad ex-situ for 8 minutes and record COF data in-situ for 2 minutes

Results - Phase II





Experimental Procedure - Phase III

Is Pad Conditioning a Reversible Process?

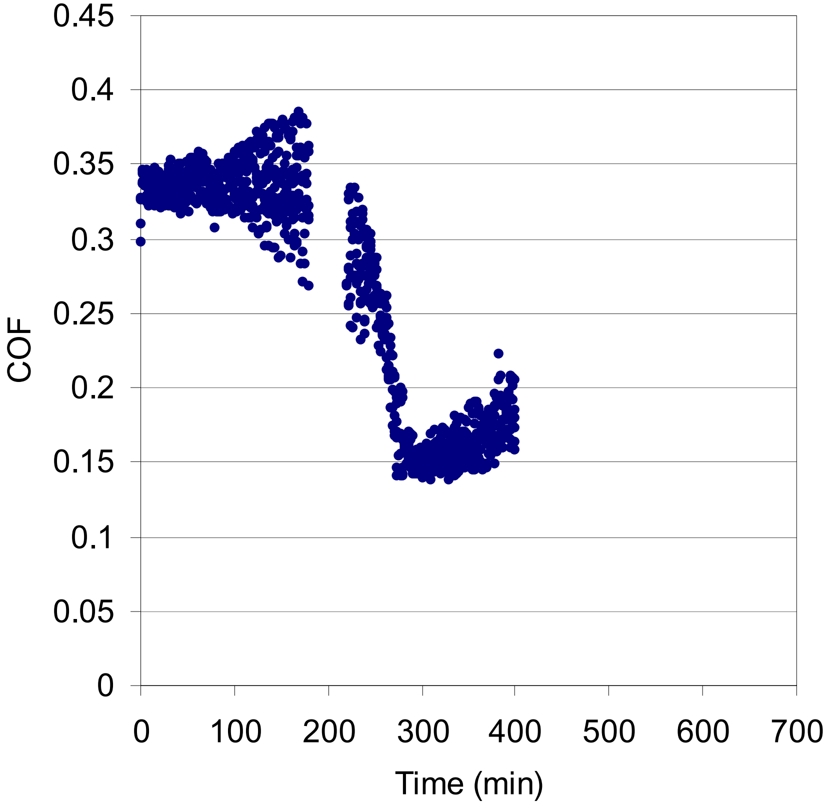
- Phase III
  - Freudenberg FX-9 pad
  - Initial pad conditioning and break-in
  - Slurry … Fujimi PL-4217 (fumed silica) at 12.5% solids
  - Polisher conditions:
    - Relative wafer-pad velocity … 0.62 meters per sec
    - Wafer pressure … 3 PSI
    - Slurry flow rate … 35 cc per minute
  - Experimental Procedure:
    - Condition pad for 8 min and record COF data for 2 min (3 repetitions)
    - Glaze the pad by recording COF data for 3 hours without conditioning
    - Condition pad for 8 min and record COF data for 2 min (4 repetitions)
    - Glaze the pad by recording COF data for 3 hours without conditioning
    - Condition pad for 8 min and record COF data for 2 min (4 repetitions)
    - Compare COF before and after pad glazing

Pad Glazing

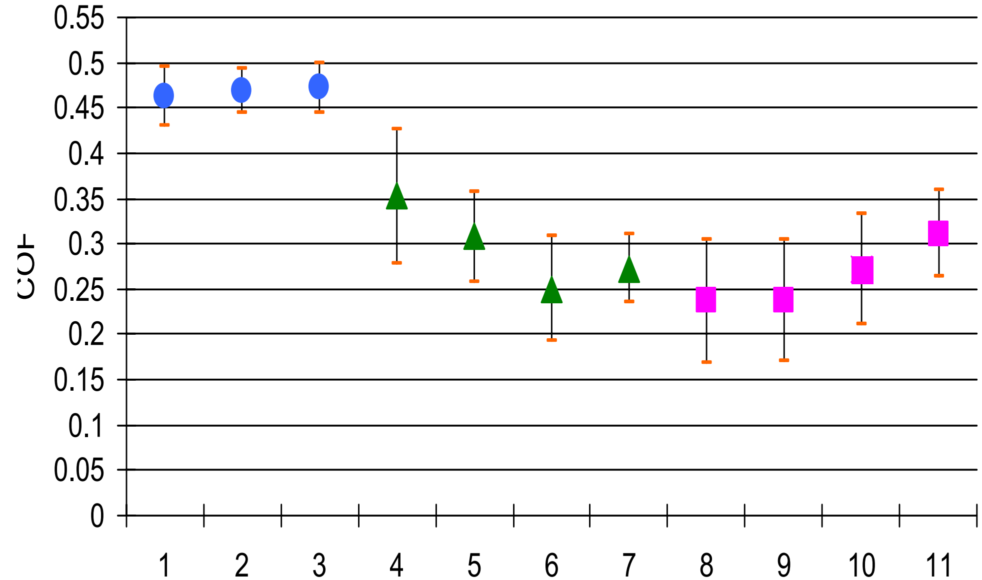
- Pad glazing is a common term used when the surface of a pad has lost its original properties, including asperities and pores.
- During polishing, the cavities and pores on the surface of a pad will get filled with slurry.
- Due to the pressure and temperature increase during polishing, the slurry starts to "glaze" the pad, or in other words, precipitate on the pad
- Pad glazing is a method to test the decay of a pad. It determines when a pad starts to decay and the rate of its decay

Results - Phase III

Combined Glaze Runs (3hr-3hr) Between 200 Grit Diamond Conditioning

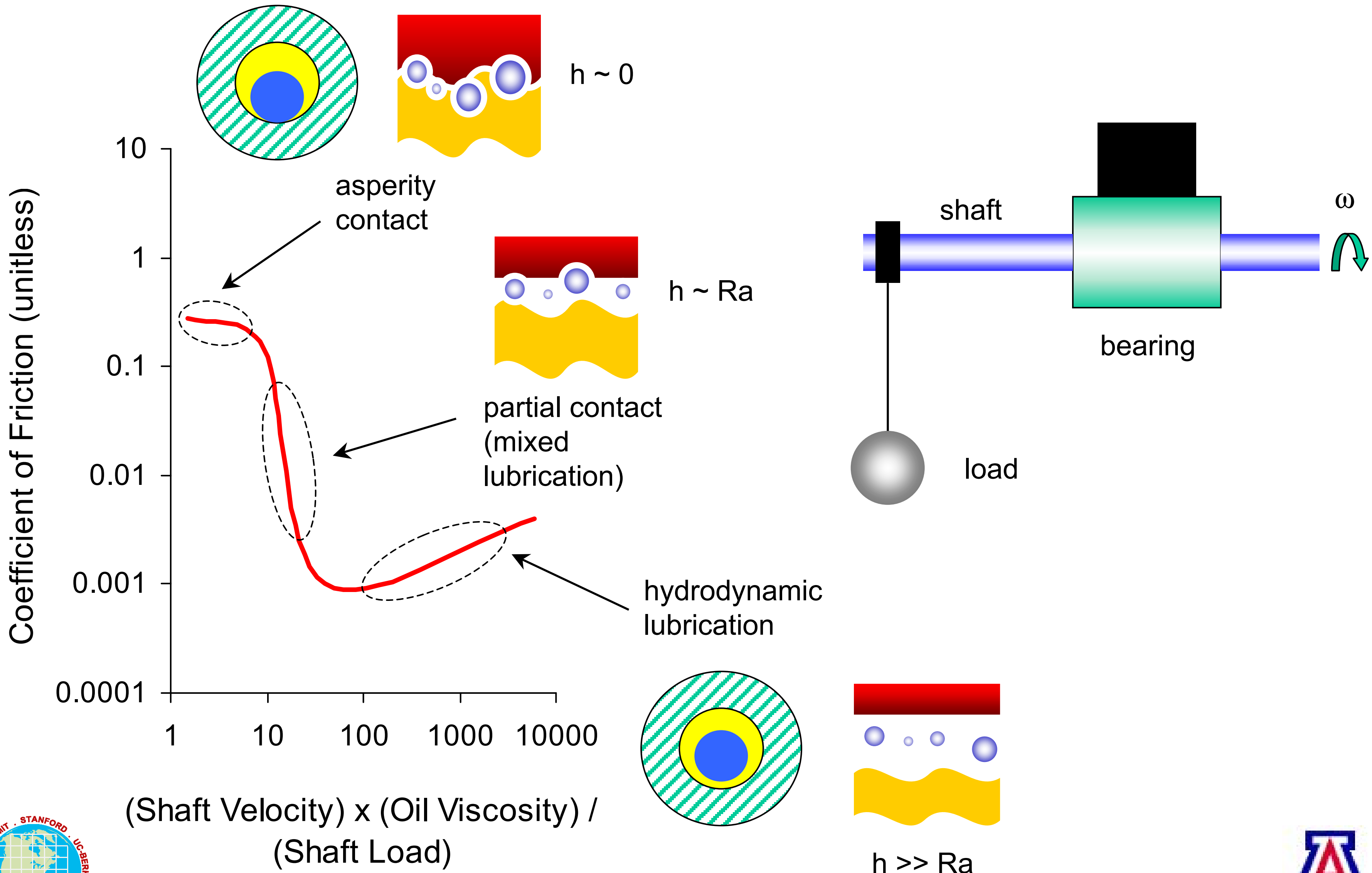


COF Before and After Pad Glazing Using 200 Grit Diamond



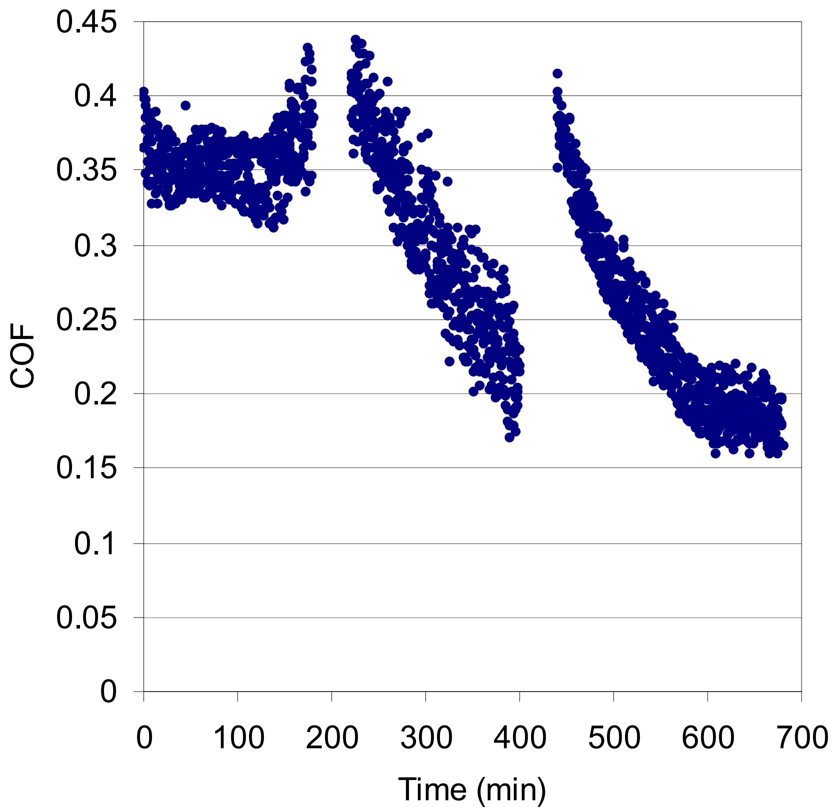
- Circles correspond to COF data prior to the first 3-hr glaze
- Triangles correspond to COF data following the first 3-hr glaze
- Squares correspond to COF data following the first 3-hr glaze

Lubrication in Journal Bearings & the Stribeck Curve

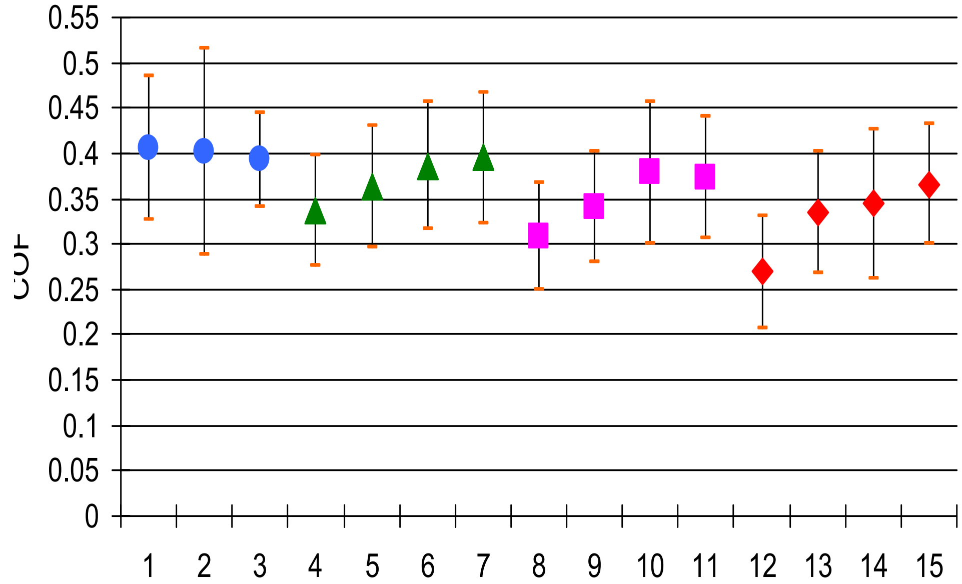


Results - Phase III

Combined Glaze Runs (3hr-3hr-4hr) Between 60 Grit Diamond Conditioning



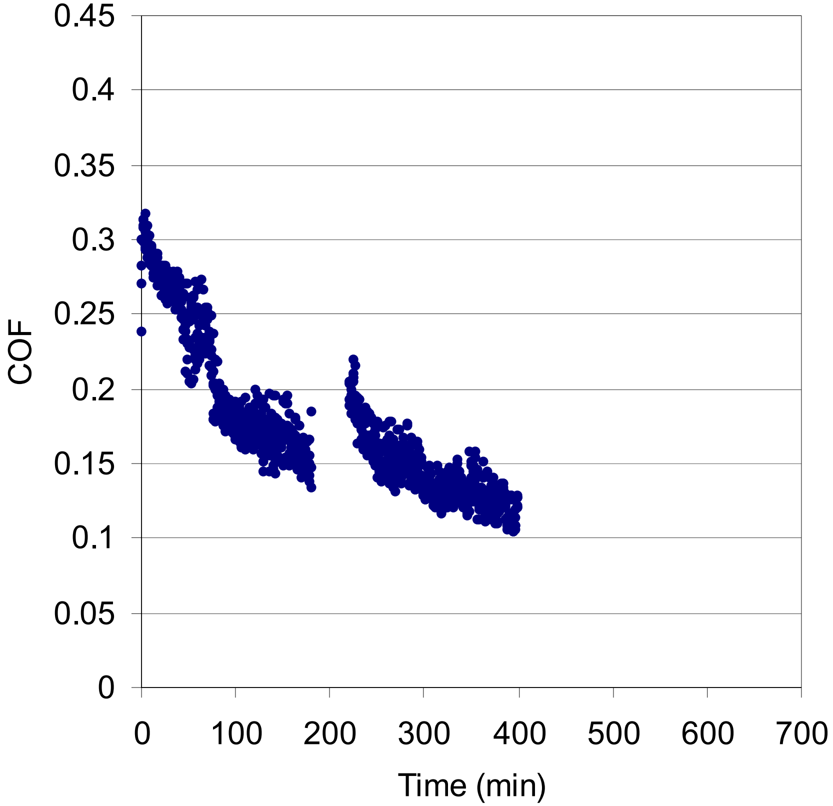
COF Before and After Pad Glazing Using 60 Grit Diamond



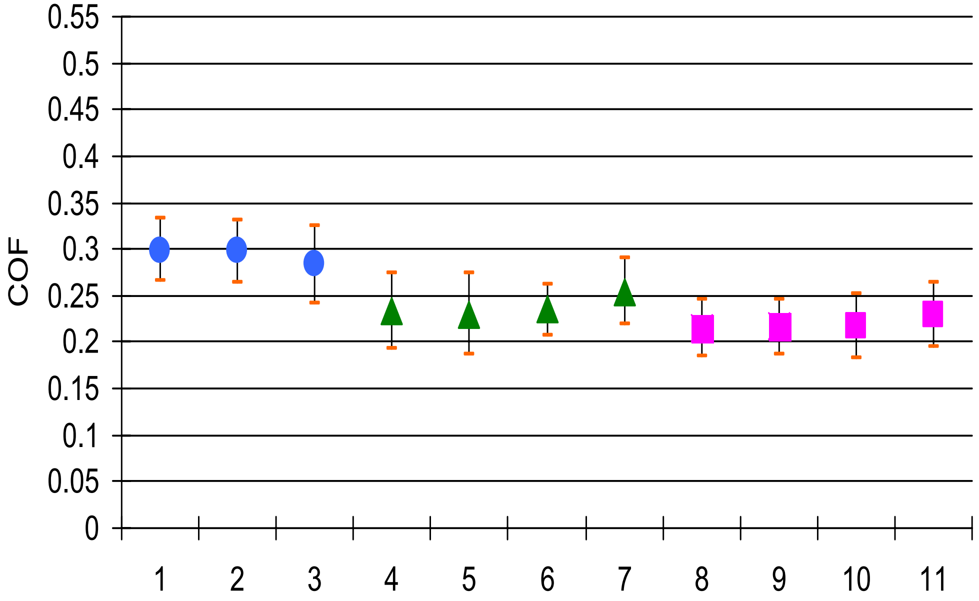
- Circles correspond to COF data prior to the first 3-hr glaze
- Triangles correspond to COF data following the first 3-hr glaze
- Squares correspond to COF data following the first 3-hr glaze

Results - Phase III

Combined Glaze Runs (3hr-3hr) Between 100 Grit Diamond Conditioning



COF Before and After Pad Glazing Using 100 Grit Diamond



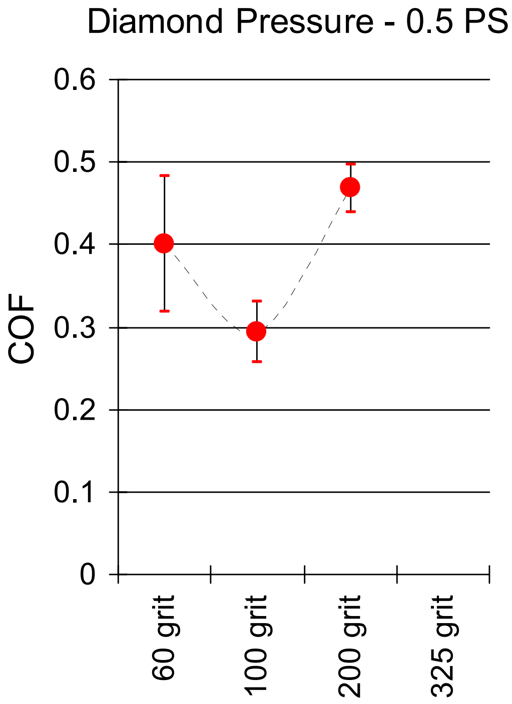
- Circles correspond to COF data prior to the first 3-hr glaze
- Triangles correspond to COF data following the first 3-hr glaze
- Squares correspond to COF data following the first 3-hr glaze

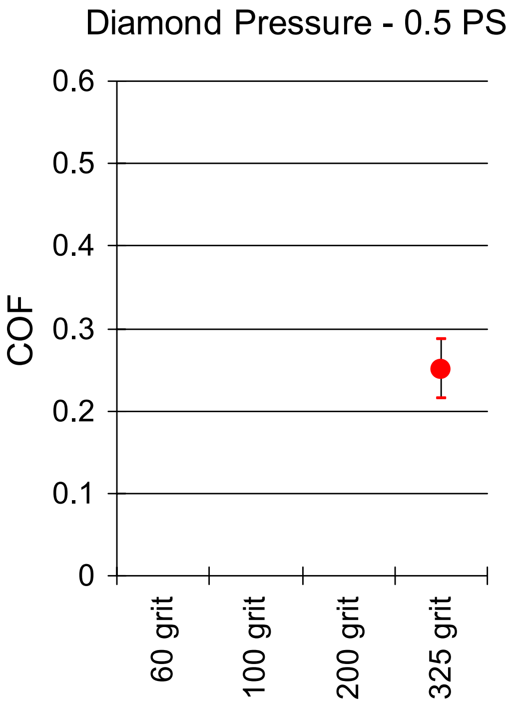
Experimental Procedure - Phase IV

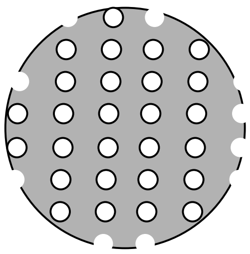
What is the effect of diamond disk geometry on COF?

- Phase IV
  - Freudenberg FX-9 pad
  - Initial pad conditioning and break-in
  - Slurry … Fujimi PL-4217 (fumed silica) at 12.5% solids
  - Polisher conditions:
    - Relative wafer-pad velocity … 0.62 meters per sec
    - Wafer pressure … 3 PSI
    - Slurry flow rate … 35 cc per minute
  - Conditioning parameters:
    - Disk speed … 50 rpm
    - Disk sweep frequency … 20 per min
    - Diamond disk … 325 grit ring shape geometry, 100 grit perforated
  - Condition pad ex-situ for 8 minutes and record COF data in-situ for 2 minutes
  - Pressure measurements of diamond disk using Tekscan Pressure mapping sensor

Results - Phase II

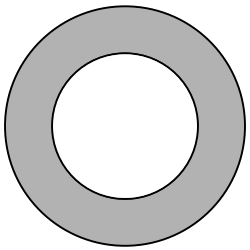






60,100 & 200 Grit perforated

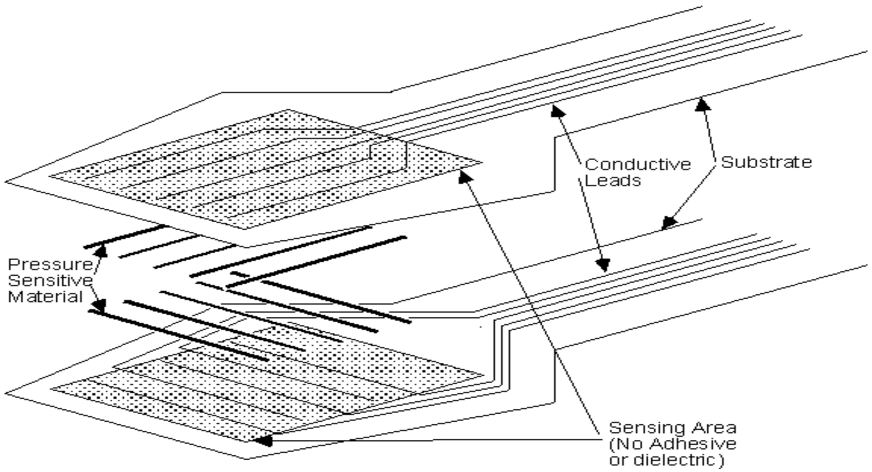
$A_{60 \text{ to } 200} = 1.5 \text{ in}^2$

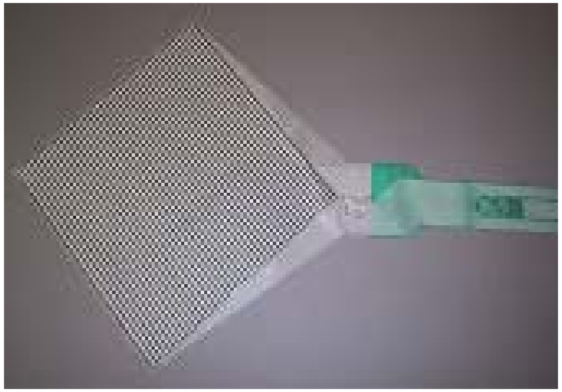


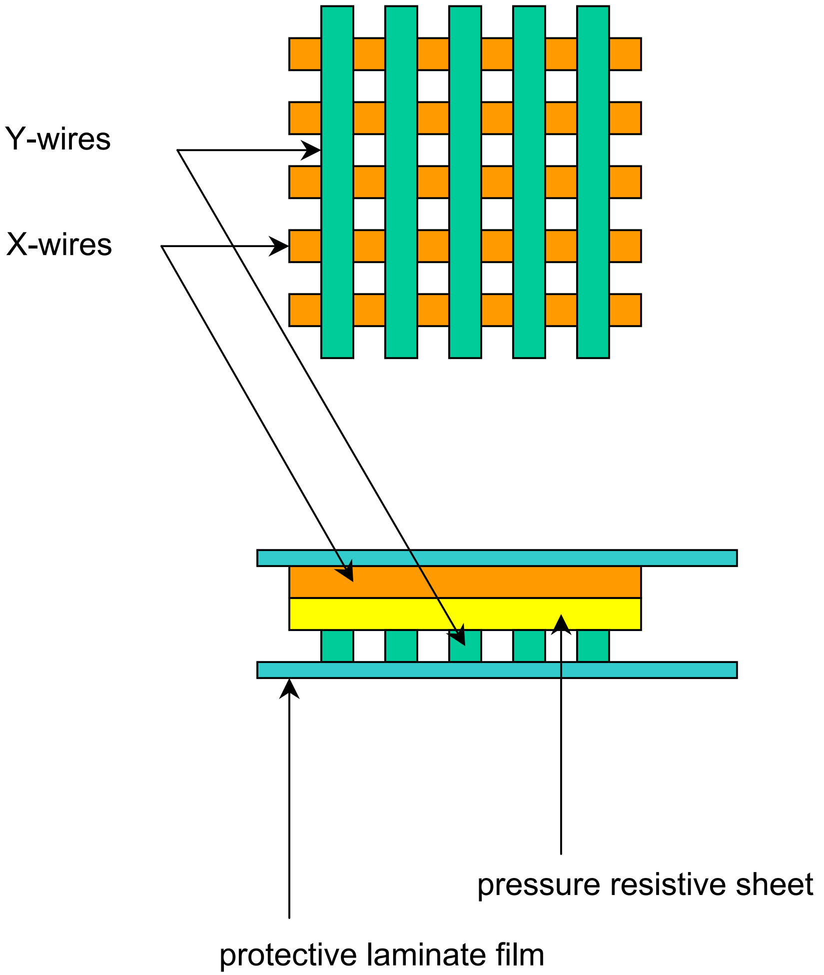
325 Grit ring shaped

$A_{325} = 1.5 \text{ in}^2$

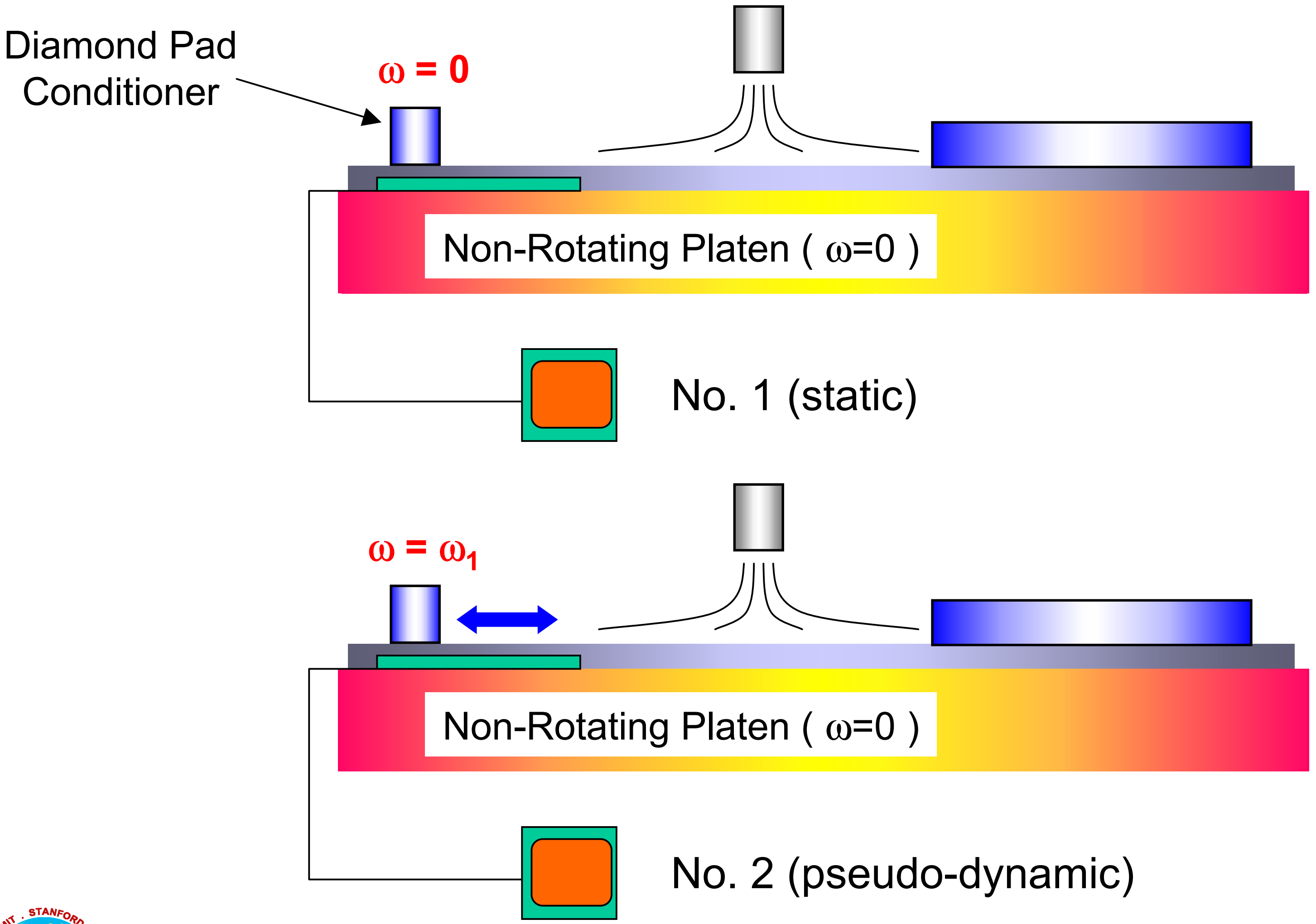
Tekscan Pressure Mapping Sensor







Pressure Mapping Procedures

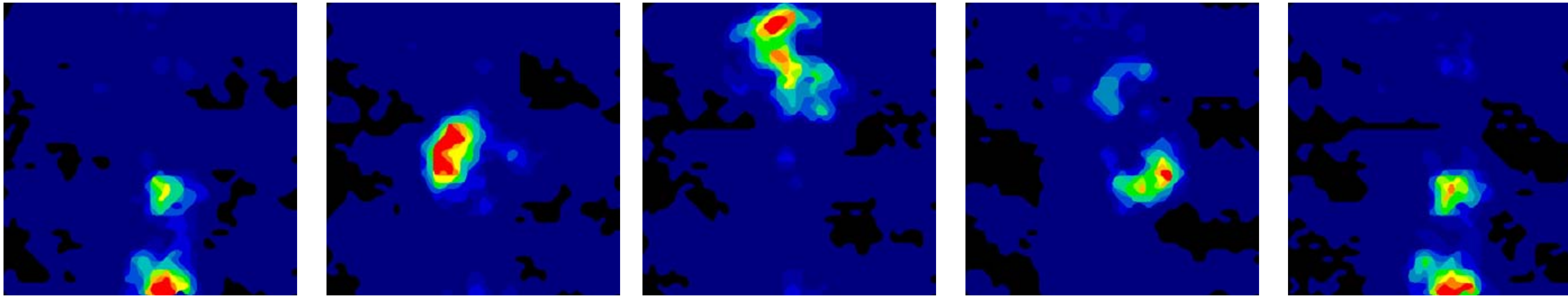


Experimental Procedure

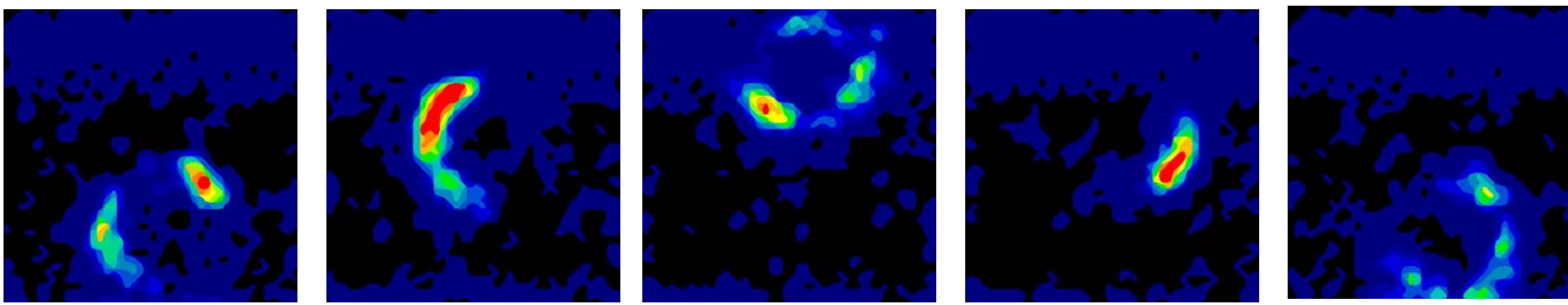
- Prior to analysis:
  - Sensor is installed & calibrated using the Tekscan Pressure Bladder System
  - Sensor is aligned & attached between platen and pad, directly under the pad conditioner (No. 1 & 2)
  - Contact is made between wafer sensor system
  - Platen is stationary during analysis
- Experimental Phases
  - Freudenberg (flat) using diluted Fujimi slurry PL-4217
    - applied pressure using 3 different springs
    - Pseudo Dynamic conditions (No. 1)
- During analysis:
  - Pressure data acquisition at pre-set applied disk pressure is taken under static conditions for the 325 grit ring and a 100 grit perforated disk
  - Diamond disk rotation is set at 30 rpm and sweep frequency is set at 30 osc/min (pseudo-dynamic)
  - Data acquisition is taken 10 frames per sec for 1 minute

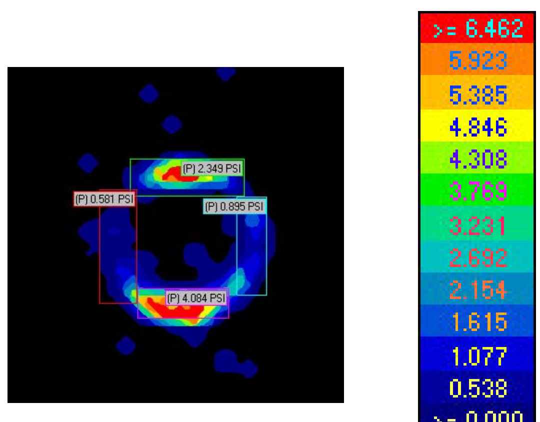
Psuedo-Dynamic Animation

325 grit diamond conditioner – ring shaped



100 grit diamond conditioner – perforated





Future Plans

- Explain the “U-Shaped” COF vs diamond grit size curve using stylus profilometry and SEM micrographs of the pad and the diamonds before and after conditioning
- Continue investigating the effect of finer diamond sizes on COF
- Continue investigating the effect of various diamond disk shapes on COF
  - Perforated
  - Ring-shaped
  - Flat
- Quantify the extent of “disk plowing” as a function of various diamond and kinematic conditions
- Determine if there is a correlation between COF and:
  - Oxide removal rate
  - Pad life
  - Diamond life
- Develop comprehensive model based on tribological arguments