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.

![Graph showing the effect of pad life on tool availability](image-url)
### Apparatus

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

- **Applied Wafer Pressure**
- **Diamond Grit Plate with Rotation & Translation**
- **Strain Gauge**
- **Sliding Friction Table**
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
• 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

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

<table>
<thead>
<tr>
<th>Diamond Mesh</th>
<th>Length (microns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>38.1</td>
</tr>
<tr>
<td>325</td>
<td>43.2</td>
</tr>
<tr>
<td>270</td>
<td>53.3</td>
</tr>
<tr>
<td>230</td>
<td>61.0</td>
</tr>
<tr>
<td>200</td>
<td>68.0</td>
</tr>
<tr>
<td>170</td>
<td>88.9</td>
</tr>
<tr>
<td>140</td>
<td>104.1</td>
</tr>
<tr>
<td>120</td>
<td>124.5</td>
</tr>
<tr>
<td>100</td>
<td>149.9</td>
</tr>
<tr>
<td>80</td>
<td>177.8</td>
</tr>
<tr>
<td>60</td>
<td>248.9</td>
</tr>
</tbody>
</table>

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

Diamond Pressure - 0.5 PSI

Diamond Pressure - 1.5 PSI

COF vs Grit

Wafer pressure

- --- 5 PSI
- --- 3 PSI
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 Striebeck Curve

\[
\text{Coefficient of Friction (unitless)}
\]

- Asperity contact
- Partial contact (mixed lubrication)
- Hydrodynamic lubrication

\[
\frac{\text{(Shaft Velocity)} \times \text{(Oil Viscosity)}}{\text{(Shaft Load)}}
\]

- \( h \sim 0 \)
- \( h \sim \text{Ra} \)
- \( h \gg \text{Ra} \)

Shaft, Bearing, Load, Angular Velocity \( \omega \)
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

Diamond Pressure - 0.5 PSI

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

- X-wires
- Y-wires
- Pressure resistive sheet
- Protective laminate film

Diagram showing the structure of the sensor with labeled parts such as conductive leads, sensing area (no adhesive or dielectric), and the layers of the sensor.
Pressure Mapping Procedures

No. 1 (static)

Non-Rotating Platen ( $\omega=0$ )

No. 2 (pseudo-dynamic)

Non-Rotating Platen ( $\omega=0$ )

Diamond Pad Conditioner
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