Effect of Conditioner Design and Polisher Kinematics on Fluid Flow Characteristics during CMP

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Problem Statement and Objective

- Fluid dynamics in CMP is **really complicated** – Too many rotating and oscillating parts – And groove designs.
- This complexity **gets exacerbated** with in-situ conditioning.
- This complexity **gets further exacerbated** when discs of varying designs are employed.
- Current CFD and other numerical simulation capabilities are **woefully inadequate** for capturing various nuances in flow patterns.
- Today we will introduce a **new experimental method based on fluorescence** to help quantify flow patterns during conditioning.
- We will focus on several case studies and explain our observations trends **qualitatively and quantitatively**:
  - Various CVD diamond disc working face designs
  - Platen velocities

Further work is ongoing!
Mechanisms of Fluid Transport in CMP

- Pad grooves, pad pores and land-area micro-texture
- Oscillatory and rotary motions of the conditioner (and the carrier head)
  - Bow wave and boundary layer around the disc (and the retaining ring)
  - Movement of fluid in and out of the disc-pad (and wafer-pad) interface
- Advection in the radial direction
- Centrifugal forces
- Centripetal forces mainly due to drag between pad and fluid
- Back-flow
  - Fluid build-up caused by surface tension at the edge of the pad
  - Conditioner (and wafer carrier) motion
Experimental Conditions

• Pad
  - DowDupont Politex – Rotating CCW at 50 or 100 RPM.
  - Break-in – 3M PB32A brush for 30 minutes at 95 RPM with platen at 50 RPM.

• Fluorescent fluid (UPW with 0.5 g/l of 4-methyl-umbelliferone) flowing at 250 cc/min with LED UV illumination

• UPW rinse at 2,000 cc/min for 30 seconds at RT between each test.

• No wafers were polished – Carrier head was disengaged

• CVD Conditioners
  - MGAM – 4S
  - MGAM – 43
  - CCW rotation at 95 RPM
  - 3-pound down-force
  - 11 sweeps per min
  - 72 seconds of conditioning

• All runs were repeated once – Differences in results were less than 4 percent in all cases!
Details on Various Sections Tested

<table>
<thead>
<tr>
<th>Location</th>
<th>Distance from Pad Center (&quot;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>13.125 – 14.375</td>
</tr>
<tr>
<td>S2</td>
<td>11.875 – 13.125</td>
</tr>
<tr>
<td>S3</td>
<td>10.375 – 11.875</td>
</tr>
<tr>
<td>S4</td>
<td>8.000 – 10.375</td>
</tr>
<tr>
<td>Sweep Stroke</td>
<td>2.60 – 14.21</td>
</tr>
<tr>
<td>Dispense Point</td>
<td>3.5</td>
</tr>
</tbody>
</table>
The Araca UVI-Z-100 System

High Resolution CCD Camera

UV – LED

UV – LED cover
The UVIZ-100 on our APD-800 Polisher

UV light source

Camera

Dyed slurry

UV - LED

Prosilica camera

Adjustable magnetic arms
CVD Discs and Procedure

**4S**

Break-in the pad with a bristle brush for 30 minutes

Perform UVIZ test on the MGAM 4S disc with platen rotating at 100 RPM – Repeat at 50 RPM.

Repeat with the MGAM 43 disc

Perform fluid thickness calibration (see next page)
All flow visualization experiments and calibrations tests were done in a darkened room – And in 1 day so as to minimize the effect of time-dependent photobleaching.
Data Analysis Flow Chart

Plot raw fluid thickness data for each section analyzed and reset the data to the origin.

Fit a curve in each section using the following equation:

\[ y = a - b \times e^{(-c \times t^n)} \]

- \( y \) = fluid thickness (mm)
- \( t \) = time (s)
- Constants a, b, c and n are fitting parameters

Calculate the hypothetical film thickness after 10 minutes (defined as MAFT which stands for “maximum attainable fluid thickness”)

Calculate the time needed to reach 90% of the MAFT (defined as TTRSS which stands for “time to reach steady-state”)

\[ y = \]
Data Analysis – 4S at 100 RPM
Raw Data and Fitted Curves
Data Analysis – 43 at 100 RPM

Raw Data and Fitted Curves

Thickness [mm] vs. Time (s)

- S1
- S2
- S3
- S4
Disc 4S – Film Thickness vs. Distance

50 RPM

100 RPM
Trend Analysis

• At the shortest time, section closest to pad center has the thickest film because fresh fluid is dispensed near that region.

• At longer times, film thicknesses:
  ✓ Closest to pad center, increase (by up to 2X) – Then they level off rapidly.
  ✓ In regions away from pad center, keep on increasing (by up to 3X) – Then they level off at a slower rate. This is due to the conditioner’s ability to draw fresh fluid from the center and carry it further out as it moves away.
  ✓ Near the edge, keep on increasing (by 5X) – Then they level off at a slower rate.

• Thicknesses near pad edge are lowest because fluid is removed from the surface as the conditioner moves over the edge.

• Higher pad angular velocity causes films near the edge to get thinner (due larger centrifugal forces) – No angular velocity dependence near the center.
Disc 43 – Film Thickness vs. Distance

50 RPM

100 RPM

Distance from Pad Center [inches]

Thickness [mm]
Disc Comparison (4S vs. 43) at 100 RPM

4S

43
Trend Analysis

• Same general trends discussed for the 4S are apparent with the 43.

• However:

  ✓ Full-face conditioner (43) has lower overall film thicknesses because it does not entrain fluid as effectively as the 4S which has vanes.
  ✓ 43 tends to impart more of a squeegeeing effect and as it moves over the edge, more fluid is expelled away.
  ✓ Due to its fluid retention characteristics, 4S generates more back-flow.
  ✓ This effect is more pronounced at 100 RPM likely because disc rotation (95 RPM) and platen rotation (100 RPM) are nearly matched.
VIDEO – Disc 4S at 100 RPM
VIDEO – Disc 43 at 100 RPM
**Time To Reach Steady State**

TTRSS ≡ Time needed to reach 90% of the maximum attainable fluid thickness (MAFT)

![Graph showing Time To Reach Steady State](image-url)
Maximum Attainable Fluid Thickness

50 RPM

100 RPM

MAFT (mm)

Sections

S1
S2
S3
S4

S1
S2
S3
S4

50 RPM

100 RPM

4S
43

4S
43

Sections
Time To Reach Steady State

50 RPM

100 RPM

Sections: S1, S2, S3, S4

TTRSS (s)

4S 43

50 RPM

100 RPM

Sections: S1, S2, S3, S4

TTRSS (s)

4S 43

50 RPM

100 RPM

Sections: S1, S2, S3, S4

TTRSS (s)

4S 43
MAFT and TTRSS Means and Ranges

- **MAFT (mm)**
  - 50 RPM
  - 100 RPM

- **TTRSS (s)**
  - 50 RPM
  - 100 RPM

- **Comparison**
  - 4S
  - 43
MAFT and TTRSS Summary

- 4S causes thicker fluid films (by 23 and 33 percent at 50 and 100 RPM, respectively) as compared to 43 – Because 4S has greater retention capabilities and generates more back-flow
- Sections near the center of the wafer track have thicker fluid
- Near the center of the pad, fluid is only slightly thinner
- Near the edge of the pad, fluid is significantly thinner
- Regarding time to reach steady-state fluid thickness conditions:
  - 4S takes longer (by 31 and 83 percent at 50 and 100 RPM, respectively) compared to 43 – Because 4S impedes and disrupts flow more effectively
  - The farther away from the pad center, the longer it takes for film thicknesses to reach SS due to the area dependence on radius (i.e. the $\Pi R^2$ effect)!

- Further work using our novel technique is ongoing with the ultimate goal being to come up with the ideal disc face designs and process conditions!
Thank You!