Characterization of Planarization Capability of Polishing Pad

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Introduction

• Local Planarization
  – Planarization efficiency, step height reduction

• Global planarization
  – Planarization length
  – Proposing a new concept for consumable characterizations: Relaxation length

• Subject used for this study: oxide CMP
  – Relative simpler
  – Easier to collect data
Local Planarization

Approach I. Planarization efficiency (PE)

\[
PE = 1 - \frac{R_T}{R_L}
\]

\[
SH(t) = SH(t=0) - (R_L - R_T)
\]

\[
SH(t) = SH(t=0) - PE \times R_L
\]

*PE is the slope in the plot of step height as function of removal in line.*

Approach II. Step height reduction as function of polishing time (removal in field)
Step Height Reduction of 250 /250 μm Structure

Pad A, B, and C are three different versions of Hard Porous Pads.
Step Height Reduction of 25/25 µm Structure

PE is feature size dependent
PE may not be a constant, could decrease with decreasing step height
Step Height Reduction of 250 /250 µm Structure

![Graph showing step height reduction and field oxide removal for different pads: Pad A / Colloidal, Pad B / Colloidal, Pad C / Colloidal, Pad C / Fumed.](chart.png)
Step Height Reduction of 25 /25 µm Structure

![Graph showing step height reduction and oxide removal in field.](image)

- Pad A / Colloidal
- Pad B / Colloidal
- Pad C / Colloidal
- Pad C / Fumed

**Step Height Reduction (25 um / 50%)**

**Oxide Removal in Field / Å**

**Step Height Remained / Å**
### Comparison Between Approaches

<table>
<thead>
<tr>
<th>Approach I (PE)</th>
<th>Approach II (SH reduction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Large feature: Pad B &amp; C perform better than Pad A</td>
<td>• Large feature: Pad B &amp; C perform better than Pad A</td>
</tr>
<tr>
<td>• Small feature: All three pads perform about the same</td>
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</tr>
<tr>
<td>• Slurry: no effect on performance</td>
<td>• Slurry: fumed silica performs better than colloidal silica</td>
</tr>
</tbody>
</table>

**Conclusions from the two approaches may not be the same**

**Approach II is a hybrid of local and global**
Global Planarization – Planarization Length

Before CMP

Local step height

SiO₂

After CMP

Global step height

Planarization Length

SiO₂

### Pattern Wafer Layout

<table>
<thead>
<tr>
<th></th>
<th>P200</th>
<th>P500</th>
<th>P50</th>
<th>P100</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td></td>
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<td>90</td>
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<td>30</td>
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<td>70</td>
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<td>50</td>
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<td>100</td>
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</table>

- **50% density**
- **100 µm pitch**

Dimensions:
- **20 mm**
- **4 mm**
Comparison of Profiles of Trench & Line

Initial film thickness ~ 20.4 KA; step height ~ 8000 A
Trench and line have similar profiles
Density Effect on Topographic Profile of Line

Initial film thickness: Pad C & B ~ 19.1 KA; IC pad ~20.4 KA
Density Effect on Topographic Profile of Line

Global step height is a function of density variation.
Relaxation Model

- Pad deformation controls the topographic profile
- Pad deformation profile can be described by exponential function

\[ \text{Thickness} = A + B_1 \exp(-C \cdot X) + B_2 \exp(-C \cdot (4000 - X)) \]

A: thickness offset
B: step height
C: relaxation constant
\(1/C\): relaxation length (RL)
4000: array dimension
Profile Transition -- Pad A

Pattern Density Effect on Profile

All fittings use the same relaxation constant (0.0017 um\(^{-1}\))
Profile Transition – Pad B and C

Pattern Density Effect on Profile

Oxide Thickness / Å

Relative position / μm

Relaxation constants: pad B 0.0015 um\(^{-1}\); pad C 0.0013 um\(^{-1}\)

Slurry has no effect on relaxation constant
Profile Transition – IC Pad

Pattern Density Effect on Profile

Relaxation constant is 0.0011 um\(^{-1}\) for all fittings
## Relaxation Length

<table>
<thead>
<tr>
<th>Pad</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>C/fumed</th>
<th>IC</th>
</tr>
</thead>
<tbody>
<tr>
<td>C/µm⁻¹</td>
<td>0.0017</td>
<td>0.0015</td>
<td>0.0013</td>
<td>0.0013</td>
<td>0.0011</td>
</tr>
<tr>
<td>RL/µm</td>
<td>590</td>
<td>670</td>
<td>770</td>
<td>770</td>
<td>910</td>
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Relaxation length is independent of pattern density
Relaxation length is independent of slurry type
Relaxation length is sensitive to the pad performance
Planarization Length (MIT)

Oxide CMP Pattern Dependent Model (Stine et al. ‘97)

- Removal rate inversely proportional to density:
  \[
  \frac{dz}{dt} = -k_p \rho v = -\frac{K}{\rho(x, y)}
  \]

- Density assumed constant (equal to pattern) until local step has been removed:
  \[
  \rho(x, y, z) = \begin{cases} 
  \rho_0(x, y) & z > z_0 - z_1 \\ 
  1 & z < z_0 - z_1 
  \end{cases}
  \]

- Final oxide thickness related to effective density:
  \[
  z = \begin{cases} 
  z_0 - \frac{Kt}{\rho_0(x, y)} & Kt < \rho_0 z_1 \\ 
  z_0 - z_1 - Kt + \rho_0(x, y)z_1 & Kt > \rho_0 z_1 
  \end{cases}
  \]

- Evaluation of pattern density \( \rho_0(x, y) \) is key to model development

The interaction length (PL) for IC1400 is 3.2 ~ 3.6 mm
Relationship between Relaxation Length and Planarization Length

\[ \frac{SH}{2.7} \]
Relationship between Relaxation Length and Planarization Length

If 90% of step height will be used to calculate PL, 
PL ~ 4.6 RL

If 85% of step height will be used to calculate PL, 
PL ~ 3.8 RL

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<td>PL (0.9) / mm</td>
<td>2.7</td>
<td>3.1</td>
<td>3.5</td>
<td>4.2</td>
</tr>
<tr>
<td>PL (0.85) / mm</td>
<td>2.2</td>
<td>2.5</td>
<td>2.9</td>
<td>3.5</td>
</tr>
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Based on MIT work, the PL of IC1400 is about 3.2 – 3.6 mm. This PL is equivalent to 85% of step height.
Summary

• Local planarization: different approaches could result in conflict conclusion.

• Global planarization:
  – Planarized wafer surface may not be really flat.
  – Planarization length is difficult to define the exact physical meaning.
  – Relaxation length could be a better terminology to define the pad long range planarization capability, no assumption involved.
  – Planarization length and relaxation length can be correlated.