FEOL CMP Process and Consumables Characterization Vehicle for 14nm Node and Beyond

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SEMATECH/SUNY Poly CNSE Advanced Planarization Center Accelerating Solutions Through Synergy
Planarization Test Masks: Past and Present

SEMATECH/MIT mask-set became the *de facto* CMP workhorse for the industry in the late 90’s

Features

- Comprehensive geometries
- Multi-layer topography

Value

- Process characterization
- Consumable benchmarking
- Standardization of results

20 years of scaling & new materials demand an updated CMP standard mask-set to meet sub-14nm challenges
New Mask-Set Development – Industry Survey

- SEMATECH/SUNY Poly CNSE Advanced Planarization Center engaged in development of next-generation, industry-standard CMP test mask with input from the industry
  - SEMATECH performed survey across CMP industry with respect to technology and macros priorities, layout geometries, metrology techniques
  - Over 90% responders graded importance of access to new CMP mask set as important or critical

<table>
<thead>
<tr>
<th>Survey Responders</th>
<th>Response Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDM</td>
<td>4.9%</td>
</tr>
<tr>
<td>Foundry</td>
<td>9.8%</td>
</tr>
<tr>
<td>Consumable Supplier</td>
<td>61.0%</td>
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<tr>
<td>Tool Supplier</td>
<td>19.5%</td>
</tr>
<tr>
<td>Academia/Government</td>
<td>4.9%</td>
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</table>
14/16 nm Geometry Bench Mark

<table>
<thead>
<tr>
<th>Layer</th>
<th>Company A</th>
<th>Company B</th>
<th>Company C</th>
<th>This Mask</th>
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<tbody>
<tr>
<td></td>
<td>CD</td>
<td>Pitch</td>
<td>CD</td>
<td>Pitch</td>
</tr>
<tr>
<td>Active</td>
<td>8</td>
<td>42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gate</td>
<td>29</td>
<td>70</td>
<td>78</td>
<td>90</td>
</tr>
<tr>
<td>Contact</td>
<td>29</td>
<td>70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>28</td>
<td>52-56</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td>Via</td>
<td>28</td>
<td>52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M2</td>
<td>28</td>
<td>54</td>
<td></td>
<td></td>
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</tbody>
</table>

- Cost effective short-loop test vehicle with node relevant geometries
FEOL Test Vehicles

<table>
<thead>
<tr>
<th>FEOL (26mm*33mm)</th>
<th>CD (nm)</th>
<th>Pitch (nm)</th>
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<tbody>
<tr>
<td>SADP fin/active</td>
<td>10</td>
<td>48</td>
</tr>
<tr>
<td>Active mandrel</td>
<td>38</td>
<td>96</td>
</tr>
<tr>
<td>Active cut</td>
<td>96</td>
<td>192</td>
</tr>
<tr>
<td>Active block</td>
<td>38</td>
<td>96</td>
</tr>
<tr>
<td>Gate</td>
<td>30</td>
<td>90</td>
</tr>
<tr>
<td>Contact</td>
<td>40</td>
<td>90</td>
</tr>
<tr>
<td>M1 /fatline</td>
<td>1k</td>
<td>1.09k</td>
</tr>
</tbody>
</table>

- SADP fin/active: node relevant
- LE gate & contact: to control complexity/cost
- LELE M1/M2: node relevant
- BEOL test vehicle will follow
FEOL Short Loop Flow

- HM1, HM2 & mandrel dep
- Mandrel litho (40/96nm) & etch (stop on HM2)
- SIT spacer dep and etch
- Cut mask litho (40/96nm) & etch (stop on HM2)
- Block litho (40/96nm)
- Etch HM2, HM1 and fin/active
- Oxide fill and CMP
- Poly dep & CMP
- Gate litho (40/96nm) & etch
- Spacer dep & etch (SiN)
- ILD 0 dep & POP CMP
- HK/MG dep & CMP (TiN/W)
- MG recess, SiN dep & CMP
- ILD 1 dep
- Contact litho (40,96nm)
- Contact etch & fill (Ti/TiN/W)
- IMD dep
- M1 litho (96nm) & etch
- M1 fill (TaN/Ta/Cu) & CMP
Evaluation of multiple materials in progress to enable SADP flexibility/scaling
FEOL Mask Layout Overview

- Range of large CD and pitch features for learning transfer from legacy mask
- Selection of simplified, e-testable devices for validation of CMP effects on devices
- Structural SRAMs with geometries relevant to different technology nodes
- Range of aggressive, industry relevant CD and pitch features for CMP evaluation

- Advanced Defect and Metrology Sector (16mm X 4mm)
- Serp/Combs Sector (16mm X 5mm)
- Device Sector (2mm X 9mm)
- Dummy Fill and Density Features over Fin Array Sector (18mm X 9mm)
- SRAM Sector (2mm X 2mm)
- Aggressive Feature Density Sector (12mm X 15mm)
- Dummy Fill Sector (14mm X 15mm)

- Miscellaneous metrology structures for state of the art metrology
- Serp/Combs structures with underlying STI level topo for opens/shorts defectivity e-testing
- Combination of dummy fill test structures and aggressive features for testing effects of underlying fin topography
- Range of small and large CMP features surrounded by dummy fill for testing effects of DF type and exclusions
Legacy Features Sector

 Provides correlation with historical data

<table>
<thead>
<tr>
<th>Name</th>
<th>Density%</th>
<th>CD/Pitch</th>
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<tbody>
<tr>
<td>L1</td>
<td>10%</td>
<td>10µm/100µm</td>
</tr>
<tr>
<td>L6</td>
<td>60%</td>
<td>0.3µm/0.5µm</td>
</tr>
<tr>
<td>L8</td>
<td>60%</td>
<td>60µm/100µm</td>
</tr>
<tr>
<td>L7</td>
<td>60%</td>
<td>0.6µm/1µm</td>
</tr>
<tr>
<td>L10</td>
<td>50%</td>
<td>100µm/200µm</td>
</tr>
<tr>
<td>L11</td>
<td>10%</td>
<td>250µm/500µm</td>
</tr>
<tr>
<td>L12</td>
<td>50%</td>
<td>500µm/1000µm</td>
</tr>
<tr>
<td>L13</td>
<td>10%</td>
<td>10µm/100µm</td>
</tr>
<tr>
<td>L9</td>
<td>10%</td>
<td>500µm/1000µm</td>
</tr>
<tr>
<td>L4</td>
<td>60%</td>
<td>6µm/10µm</td>
</tr>
<tr>
<td>L2</td>
<td>10%</td>
<td>1µm/10µm</td>
</tr>
<tr>
<td>L5</td>
<td>90%</td>
<td>9µm/10µm</td>
</tr>
<tr>
<td>L3</td>
<td>30%</td>
<td>3µm/10µm</td>
</tr>
</tbody>
</table>

Provides correlation with historical data
Aggressive Density Macros

Evaluate CMP consumable interaction with topography to provide planarization windows across a range of CD & density.
Dummy Fill Macros - Examples

Characterize effect of dummy fill density, shape and exclusion on planarization of small and large structures

Different Dummy Fill Patterns

- Staggered Fill
- Regular Fill
- Strench Fill
- Fin Array Fill

Fin Arrays

Fin Arrays +Large Pads
Simple E-test Macros Examples

Test influence of CMP and post-CMP cleaning on electrical properties of films

- Large Active and Poly
- Shorted Pads
- Open Pads
- VdP
- Mobility Extraction
- Contact Chains
Serp/Combs and Opens/Shorts Line Macros

Detect open and short defects by e-test and monitor post-CMP line erosion, corrosion, and dendritic growth

Arrays with different area, underlying topo, CD and pitch
Simplified Functional FinFET Devices

- Enable direct correlation of physical and e-test data

Range of nested and isolated devices to test
Advanced Metrology: Patterning Grating & Overlay

- Simulate the metrology challenges for Quad/Hexa/Octa-patterning by making DOEs of complex period mandrels for SADP (L40P100)

49 grating SADP and SAQP module

Quad Pat: All cases up to 6nm CD and OVL step 1

Overlay – AIMS & SCOL
To cover current and future overlay methodologies
Defect Array: 14nm SRAM Cell with Intentional Defects

- Large SRAM cells creatively designed to enable printing of challenging defects
- Includes various sizes and types of defects
Reticle Enhancement Technique - OPC

- Optical proximity correction (OPC)
  - Modifications to mask features which can improve:
    • Printability onto the wafer
    • Increase process control
    • Improve yield

- Two types: Rule-based OPC vs Model-based OPC
  - Rule based OPC
    • Device features are modified based on a set of predetermined design rules
    • Suitable for less aggressive mask designs
  - Model based OPC
    • Uses lithography process analysis to develop a corrections model
    • Suitable for aggressive mask designs

Model based OPC was applied to Planarization Center CMP mask
Summary

- SEMATECH/SUNY Poly CNSE Advanced Planarization Center actively engaged in development of new industry standard CMP oriented test vehicle for 14nm and beyond
- Test vehicle will consist of comprehensive array of topographic and e-testable features for CMP process development, consumables testing and metrology optimization
- FEOL macro design completed and validated by selected industry members
- Finalized OPC model and ready for transfer to glass
- BEOL CMP test vehicle will follow