THE DAWN OF 450MM PRODUCTION
BATCH & SINGLE WAFER EQUIPMENT / PROCESS EXPLORATION

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Batch & single wafer equipment / process exploration
OUTLINE

› 300 mm to 450 mm transition

› Batch furnace
  • Hardware
  • Temperature characterization
  • Process characterization

› Single wafer platform
  • Hardware & performance

First question to address:
What’s a furnace?

G450C, located at CNSE, Albany, NY
**A VERTICAL FURNACE**

**Actions:**
- Add carrier with wafers
- (Store material in front end)
- Move material into quartz boat
A VERTICAL FURNACE

Actions:
- Elevate boat into reactor
- Add reactants
- Heat up reactor
A VERTICAL FURNACE

Actions:
• Stabilize temperature
• Process wafers
• Purge reactor
• Cool down reactor
A VERTICAL FURNACE

Actions:
- Unload boat
A VERTICAL FURNACE

**Actions:**

- Cool down wafers
- (Stock wafers)
- Move wafers back to transport carrier
SIZE TRANSITION CHALLENGES

› Cycle time

› Size of the wafer

› Consumption

› Foot print

› Maintenance
  • Weight / size!

Load port

Robot / storage

Loading stage

- Larger thermal mass
- Thermal uniformity
- Depletion / diffusion
- Stress/slip

- Power
- Gases / chemicals
- Cooling water

- Larger thermal mass
- Heat load

- Cooling water
- Purge gas
THE FURNACE

Single Reactor, 100P
- **Dry** oxidation
- **Wet** oxidation
- **H$_2$** cure
- In situ **DCE clean**

Front module
- Mini environment
- Load port
- Filler storage

Rear module
- Mini environment

Reactor Exchange Tool
## TEMPERATURE CHARACTERIZATION

### Considerations

<table>
<thead>
<tr>
<th>INCREASE parameter:</th>
<th>PRO</th>
<th>CON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stabilization time</td>
<td>Layer uniformity  ↑</td>
<td>Process time ↑</td>
</tr>
<tr>
<td>Reactor standby temperature</td>
<td>Process time  ↓</td>
<td>Maintenance ↑</td>
</tr>
<tr>
<td>Cool down blower speed</td>
<td>Handling time ↓</td>
<td>- Sound level ↑</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Particles, Stress ↑</td>
</tr>
<tr>
<td>Elevator speed</td>
<td>Handling time ↓</td>
<td>Particles, Stress ↑</td>
</tr>
</tbody>
</table>

### Characterization:

- Pre-process wafer stabilization time
- Post process wafer cool down

### Experimental

- Operational furnace
- Thermocouple wafers
CHARACTERIZATION: EXPERIMENTAL

› Pre-process:
  • Within wafer
  • Wafer to wafer

› Post-process:
  • Boat pull temperature
  • ME blower speed
  • Boat elevator speed

Standby temperature: 600°C
Pull temperature
Elevator speed
Air flow: Blower speed
Mini environment
Reactors
STABILIZATION: WITHIN WAFER

- Stable within 2°C
- Notch = 12 h

Graph showing temperature ($T$ in °C) over time ($t$ in min) with different time constants (TC). The graph indicates stability and the necessary time for stabilization.
STABILIZATION: WAFER TO WAFER

- Different entry times
- Stable set point
- Stable within 2°C

Graph showing temperature (T) over time (t) with labels for top, center, and bottom temperatures. The graph illustrates the stabilization process with different entry times and stable set points, achieving stability within 2°C.
VARYING PULL CONDITIONS: TEMPERATURE

Cool down time:
- In reactor?
- In Mini environment?

Graph showing cooling times for different temperatures: Bottom, 600°C, Bottom, 700°C, Bottom, 800°C, Center, 800°C, Top, 800°C.

Independent of pull $T$.
VARYING PULL CONDITIONS: BLOWER SPEED

Cool down:
- Radiation
- Significant: Active cooling
VARYING PULL CONDITIONS: ELEVATOR SPEED

Top wafer exits last
Little effect

\( T(\text{°C}) \) vs. \( t \text{ (min)} \)

- Red: Top, \( x \text{ mm/min} \)
- Dotted red: Top, \( 2x \text{ mm/min} \)
- Dashed: Center, \( 2x \text{ mm/min} \)
- Black: Bottom, \( 2x \text{ mm/min} \)
- Light blue: Top, \( 3x \text{ mm/min} \)
PROCESS CHARACTERIZATION: OXIDATION

› **Dry oxidation**
  - 10 nm
  - Standby temperature: 650°C
  - Process temperature: 900°C

› **Wet oxidation**
  - 45 nm
  - Standby temperature 650°C
  - Process temperature 900°C
## PROCESS CHARACTERIZATION: RESULTS

<table>
<thead>
<tr>
<th>Quantity</th>
<th>$&lt;d&gt;$</th>
<th>WiW</th>
<th>$&lt;WiW&gt;$</th>
<th>WtW</th>
<th>RtR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unit</td>
<td>nm</td>
<td>3σ %</td>
<td>3σ %</td>
<td>3σ %</td>
</tr>
<tr>
<td></td>
<td>Process</td>
<td>Dry</td>
<td>Wet</td>
<td>Dry</td>
<td>Wet</td>
</tr>
<tr>
<td>Bottom</td>
<td>Dry</td>
<td>10.3</td>
<td>44.8</td>
<td>3.3</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>450mm : 300 mm</td>
<td>Dry</td>
<td>Wet</td>
<td>Time</td>
<td>1.5</td>
</tr>
<tr>
<td>Center</td>
<td>Wet</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Top</td>
<td></td>
<td>2.6</td>
<td>1.4</td>
<td>1.4</td>
<td>0.6</td>
</tr>
</tbody>
</table>

### Dependency:
- Decrease in WiW uniformity bottom to top
PROCESS CHARACTERIZATION: WIW DOWN-BOAT

Reactors dilution increase (dry oxidation)

- **Improves** uniformity
- **Increases** process time
### PROCESS CHARACTERIZATION: FILLER USAGE

- Minimize: storage / wafer cost / cycle time

#### Dry oxidation experiment:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>(&lt;d&gt; (nm))</th>
<th>WiW (3σ %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run</td>
<td>Both</td>
<td>Full load</td>
</tr>
<tr>
<td>D1</td>
<td>10.3-10.4</td>
<td>0.4</td>
</tr>
<tr>
<td>D2</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>D3</td>
<td></td>
<td>3.3</td>
</tr>
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</table>

#### Wet oxidation experiment:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>(&lt;d&gt; (nm))</th>
<th>WiW (3σ %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run</td>
<td>Both</td>
<td>Full load</td>
</tr>
<tr>
<td>W1</td>
<td>45-50</td>
<td>0.8</td>
</tr>
<tr>
<td>W2</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>W3</td>
<td></td>
<td>3.2</td>
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</table>
FURNACE SUMMARY

› Batch furnace
  • Fully operational for process development
    • Process results comparable to 300mm equipment
  • No full load required for < 100 product wafer processes
  • Useful in wafer development process

› Benefits for smaller wafer size equipment
  • Logistic overhead
  • Particles
  • Mini-environment design
  • Fast-ramp design
  • Heated flange design
And now for something completely different.
SINGLE WAFER PLATFORM: XP8-450™

Front end
- Wafer loading
- Post process wafer cool down
- Notch alignment

Wafer handling chamber
- Wafers from loading to process chamber
- Wafers between process chambers

A dual chamber station
- PECVD
- Low k
- UV Cure
- PEALD
PROCESS RESULTS

- PECVD of oxide and nitride
- Statistics on 40 runs
- Runs performed over a period of a year

<table>
<thead>
<tr>
<th>Process</th>
<th>$&lt;d&gt;$</th>
<th>$&lt;\text{WiW}&gt;$</th>
<th>Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxide</td>
<td>0.35</td>
<td>1.0</td>
<td>-95</td>
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<tr>
<td>Nitride</td>
<td>0.07</td>
<td>0.5</td>
<td>490</td>
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</table>
XP8-450™ SUMMARY

› Installed base with four different modules
  ● PECVD functional and stable
  ● PEALD, low k, UV cure under install

› Relation to smaller size wafer equipment
  ● 450 mm is upscale of 300 mm platform
  ● Upscale of processes show similar results
  ● Current tool illustrates that quick shift to 450 mm is possible when needed
Thanks to the large team of people involved, from ASM and all these institutions: