Process Development of Sidewall Spacer Features for sub-300nm Dense Silicon FinFETs

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To achieve uniform sub-300nm critical dimensions for future FinFETs. A process was developed to demonstrate lithography techniques which utilize resist overexposure, an aluminum hard mask, nitride sidewall spacers and, finally, a reactive ion etch to transfer the nitride patterns to the silicon.
Proposed Process Flow

- Wafer cleaning.
- Thermally grow 4000Å wet SiO₂.
- Spin coat I-CON 7 BARC @ 1500Å.
- Deposit ~1000Å of pure aluminum.
- Spin coat diluted OiR620 PR @ 5600Å.
Proposed Process Flow

- Expose FEM to determine the desired over-exposure dose and focus.

- RIE BARC.
Proposed Process Flow

1. **RIE aluminum.**
2. **RIE oxide.**
3. **Deposit 2000Å of nitride.**
4. **Strip aluminum.**
Proposed Process Flow

- **RIE nitride.**
- **Strip oxide.**
- **Strip nitride.**
- **RIE Silicon.**

Nitride spacer

$L = S = 200\text{nm}$

Nitride spacers

$400\text{nm}$

$200\text{nm}$
Optimizing BARC for Minimum Reflectivity

- The PROLITH swing curve simulation for the resist on BARC on aluminum that resulted in high contrast features that can be transferred to the aluminum.

- Optimal BARC thickness is found to be 150nm for the OiR620 thickness.
300/500nm duty cycle on a 800nm pitch.

Mask Design – Various Pitch and Duty Cycles

Horizontal array
Oxide growth: A 4000Å layer of thermal oxide was grown on of the process wafers.

<table>
<thead>
<tr>
<th>Wafer ID</th>
<th>Mean (Å)</th>
<th>Std.dev.</th>
<th>Min (Å)</th>
<th>Max (Å)</th>
<th>Range (Å)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>3982.3</td>
<td>23.3 (0.58%)</td>
<td>3941</td>
<td>4042</td>
<td>101</td>
</tr>
<tr>
<td>A2</td>
<td>3994.3</td>
<td>23.0 (0.57%)</td>
<td>3951</td>
<td>4043</td>
<td>92</td>
</tr>
<tr>
<td>A3</td>
<td>3961.4</td>
<td>21.0 (0.52%)</td>
<td>3925</td>
<td>4005</td>
<td>80.3</td>
</tr>
<tr>
<td>A4</td>
<td>3980.3</td>
<td>22.0 (0.54%)</td>
<td>3937</td>
<td>4019.7</td>
<td>82.8</td>
</tr>
</tbody>
</table>

Aluminum thickness measurement (via SEM): ~1300Å, used with Resmap data to determine a thickness standard deviation of 2.7%.
Focus-Exposure-Matrix (FEM) was performed to analyze the process latitude of the ASML stepper. Center dose is set at 150mj ±10mj and center focus is set at -0.5um ± 0.1um. Numerical aperture value is set to 0.6, sigma inner and outer are set to 0.535 and 0.9, respectively.

The best dose and focus is found to be optimal at 170mj and -0.4um, where it overexposed the desired 400X500nm features on mask to be 280X570nm L/S.
SpectraSuite software is used to detect the intensity profile.

- **Step 1**: 15 second stabilization step to flow the appropriate gases.
- **Step 2**: Initial aluminum native oxide breakthrough for 8 seconds.
- **Step 3**: More aluminum native oxide breakthrough + actual etch of the 1300Å aluminum layer.
- **Endpoint**: The run is terminated once the bottom oxide etch is observed.
**Aluminum Etch (OM)**

**Before aluminum etch**
- 1300 Å aluminum on 4000Å oxide
- Patterned resist on aluminum
- Mag. = 100X

**After aluminum etch (Using Endpoint detection)**
- 4000Å Oxide
- Aluminum lines
- Mag. = 100X
Oxide Etch Rate

Oxide etch rate: ~608Å/min.
Photoresist etch rate: ~1111Å/min.

Oxide etch rates were performed on dummy wafers.
P-5000 Chamber C (With pure aluminum mask)
Run 1: 170sec. → Cleared (4000Å oxide).
Pictures below show successful oxide RIE patterning with the evaporated aluminum mask.
### Oxide Etch in DryTek Chamber vs. P-5000 Chamber C (SEM)

<table>
<thead>
<tr>
<th>DryTek Quad Chamber 3</th>
<th>P-5000 Chamber 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxide lines on silicon</td>
<td>Aluminum mask on oxide mandrel</td>
</tr>
<tr>
<td>L = 276nm  Mag. = 16.98KX</td>
<td>Stage = 90°  Mag. = 7.31KX</td>
</tr>
<tr>
<td>S = 638nm  Stage = 90°</td>
<td>L = 221nm  Mag. = 7.31KX</td>
</tr>
<tr>
<td>P= 914nm  500X500 on mask</td>
<td>S = 612nm  Stage = 90°</td>
</tr>
<tr>
<td></td>
<td>P= 832nm  400X500 on mask</td>
</tr>
</tbody>
</table>

Oxide mandrel thickness =~1700Å

Oxide mandrel thickness =~4000Å

Evaporated Al mask thickness =~1300Å
Nitride deposition recipe:

<table>
<thead>
<tr>
<th>Tool</th>
<th>LPCVD Furnace</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recipe</td>
<td>Nitride 810C</td>
</tr>
<tr>
<td>Base Pressure</td>
<td>68mT</td>
</tr>
<tr>
<td>Dep. Pressure</td>
<td>297mT</td>
</tr>
<tr>
<td>DCS</td>
<td>160sccm</td>
</tr>
<tr>
<td>NH₃</td>
<td>190sccm</td>
</tr>
<tr>
<td>Time</td>
<td>33 min.</td>
</tr>
<tr>
<td>Measured Thickness</td>
<td>~1800Å</td>
</tr>
<tr>
<td>Measured Dep. Rate</td>
<td>~55Å/min</td>
</tr>
</tbody>
</table>

ASM LPCVD Furnace. device wafers + 1 monitor wafer with 4000Å oxide.
Nitride Deposition (Cont.)

Oxide lines on silicon

- Oxide mandrel
- Silicon
- Mag. = 100X
- Mag. = 4.14KX
- Stage = 64.1°

Nitride deposition on oxide and silicon

- Nitride on mandrel/Si
- Mag. = 100X
- Mag. = 3.77KX
- Stage = 67.1°
- Bumpy nitride surface

- Nitride on oxide mandrel/Si
- Mag. = 4.0KX
- Stage = 75°
Nitride Etch Rate

\[ y = -2440x + 1750 \]

**Recipe:**
- Tool: Drytek Chamber 2.
- Power: 250W.
- Pressure: 40mT.
- CHF3: 30 sccm.
- SF6: 30 sccm.
- Etch rate: ~2440Å/min.
Nitride Etch (Cont.)

30 seconds etch (Under etched)

- Measured nitride thickness = ~400 Å
- Stage = 66.6°
- Mag. = 7.41KX

40 seconds etch (Over etched)

- Measured nitride thickness = Under 100 Å
- Stage = 70.7°
- Mag. = 4.49KX

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Stage = 70.7°
## Nitride Deposition & Etch (Proposed vs. Actual)

<table>
<thead>
<tr>
<th></th>
<th>Proposed</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Oxide mandrel</strong></td>
<td><img src="image1" alt="Proposed Oxide mandrel" /></td>
<td><img src="image2" alt="Actual Oxide mandrel" /></td>
</tr>
<tr>
<td><strong>Nitride film</strong></td>
<td><img src="image3" alt="Proposed Nitride film" /></td>
<td><img src="image4" alt="Actual Nitride film" /></td>
</tr>
<tr>
<td><strong>Nitride deposition</strong></td>
<td><img src="image5" alt="Proposed Nitride deposition" /></td>
<td><img src="image6" alt="Actual Nitride deposition" /></td>
</tr>
<tr>
<td><strong>L = S = 200nm</strong></td>
<td><img src="image7" alt="Proposed L = S = 200nm" /></td>
<td><img src="image8" alt="Actual L = S = 200nm" /></td>
</tr>
<tr>
<td><strong>Nitride etch</strong></td>
<td><img src="image9" alt="Proposed Nitride etch" /></td>
<td><img src="image10" alt="Actual Nitride etch" /></td>
</tr>
<tr>
<td><strong>Nitride spacers</strong></td>
<td><img src="image11" alt="Proposed Nitride spacers" /></td>
<td><img src="image12" alt="Actual Nitride spacers" /></td>
</tr>
<tr>
<td><strong>Mandrel removal</strong></td>
<td><img src="image13" alt="Proposed Mandrel removal" /></td>
<td><img src="image14" alt="Actual Mandrel removal" /></td>
</tr>
</tbody>
</table>

**Mag.** = 3.77KX  
**Stage** = 67.1°  

**Nitride on oxide mandrel/Si**  
**Mag.** = 4.0KX  
**Stage** = 75°  
**Bumpy nitride surface**  

**Mag.** = 7.41KX  
**Stage** = 66.6°  
**Oxide mandrel**  
**Nitride spacers**
Summary

- Patterning through annular illumination is successful to image 280nm CD.
- Aluminum hard mask is excellent for oxide patterning with an anisotropic profile.
- Aluminum over-etch proved beneficial for achieving a 211nm mandrel CD.
- Nitride deposition shows a conformal yet textured profile over the oxide mandrel.
- Nitride etch resulted in non-uniform opening between nitride sidewall spacers due to the previous nitride deposition texture.
- DOE is required for the nitride deposition and etch for optimal sidewall profile.
- Due to the project constraints, the silicon etch process was not completed.
Future Work

• Continue this investigation to develop a full fabrication process and electrically characterize finFET devices.

• Consider utilizing a hard mask under the nitride spacer to be transferred to the silicon.
