Wafer Cleaning and Oxide Growth Laboratory

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Surface Particle Counts
RCA Clean
Oxide Growth
Furnace Operation
Oxide Thickness Measurement
CLEAN AND OXIDE GROWTH

TENCORE SURF SCAN

Gives total surface particle count and count in 4 bins <0.5, 0.5 to 2.0, 2.0-10, >10. Bin boundary can be selected. Edge exclusion eliminated count from near the edge of the wafer.
CLEAN AND OXIDE GROWTH

SURFACE PARTICLE COUNTER

PARTICLE SIZE IS RELATED TO SCATTER ANGLE

ROTATING MIRROR SCANNER

LASER

DETECTOR ARRAY AND COUNTER

WAFER WITH PARTICULATES
### Example Surface Particle Count Data

**Before Cleaning (75 mm)**

<table>
<thead>
<tr>
<th>Size Range (µm)</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 - 0.5</td>
<td>104</td>
</tr>
<tr>
<td>0.5 - 2.0</td>
<td>562</td>
</tr>
<tr>
<td>2.0 - 10</td>
<td>19</td>
</tr>
<tr>
<td>&gt;10</td>
<td>2</td>
</tr>
</tbody>
</table>

**After Cleaning (75 mm)**

<table>
<thead>
<tr>
<th>Size Range (µm)</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 - 0.5</td>
<td>10</td>
</tr>
<tr>
<td>0.5 - 2.0</td>
<td>4</td>
</tr>
<tr>
<td>2.0 - 10</td>
<td>3</td>
</tr>
<tr>
<td>&gt;10</td>
<td>0</td>
</tr>
</tbody>
</table>
CLEAN AND OXIDE GROWTH

RCA CLEAN WAFERS

**APM**

\[
\begin{align*}
\text{H}_2\text{O} & - 4500\text{ml} \\
\text{NH}_4\text{OH} & - 300\text{ml} \\
\text{H}_2\text{O}_2 & - 900\text{ml} \\
75 \degree \text{C}, & 10 \text{ min.}
\end{align*}
\]

**DI water rinse, 5 min.**

**DI water rinse, 5 min.**

**HPM**

\[
\begin{align*}
\text{H}_2\text{O} & - 4500\text{ml} \\
\text{HCL} & - 300\text{ml} \\
\text{H}_2\text{O}_2 & - 900\text{ml} \\
75 \degree \text{C}, & 10 \text{ min.}
\end{align*}
\]

**DI water rinse, 5 min.**

**What does RCA stand for?**

**PLAY**

**ANSWER**

DI water rinse, 5 min.

H\textsubscript{2}O - 50 HF - 1 60 sec.

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CLean and Oxide Growth

RCA Clean Details

- Water (H₂O), hydrogen peroxide (H₂O₂), and ammonium hydroxide (NH₄OH) mixture (APM bath, for ammonium-peroxide-mixture). Removes organics from the wafer, such as fingerprints, residual resist etc.
  - APM bath temperature 75-85°C
  - H₂O₂ is unstable and breaks down into H₂O and O the O is very reactive and protects the wafer from being etched in the strong base (NH₄OH)
  - Our H₂O₂ is unstabilized so it has a short shelf life, bubbles indicate good H₂O₂
  - Follow with a DI water cascade rinse
- Dilute hydrofluoric acid bath at room temperature. Removes oxides formed in the baths as well as native oxide under previously removed contaminants
  - Follow with a DI water cascade rinse
- Water (H₂O), hydrogen peroxide (H₂O₂), and hydrochloric acid (HCl) mixture (HPM bath, for hydrochloric-peroxide-mixture). Removes inorganic residues and heavy metals.
  - HPM bath temperature 75-85°C
  - H₂O₂ is unstable and breaks down into H₂O and O the O is very reactive and protects the wafer from being etched in the strong acid (HCl)
  - Our H₂O₂ is unstabilized, short shelf life, bubbles indicate good H₂O₂
  - Follow with a DI water cascade rinse
- Dry using the spin rinser-dryer (SRD)
Chemical Reactions:

**Dry Oxidation:**  
\[ \text{Si} + \text{O}_2(\text{gas}) \rightarrow \text{SiO}_2 \]  
Used for thinner oxides and oxides of high quality

**Wet Oxidation:**  
\[ \text{Si} + 2\text{H}_2\text{O}(\text{gas}) \rightarrow \text{SiO}_2 + 2\text{H}_2(\text{gas}) \]  
Used for thicker oxides because growth rate is higher
Thickness of Si consumed:
\[ X_s = X_{ox} \cdot \frac{N_{ox}}{N_{Si}} \]
\[ X_s = 0.44X_{ox} \]

Original Si interface

\[ N_{oxide} = 2.2 \times 10^{22} \text{ cm}^{-3} \]
\[ N_{silicon} = 5 \times 10^{22} \text{ cm}^{-3} \]
\[ = 0.44 \]

Example: Oxide thickness grown, \( X_{ox} = 1000\text{Å} \)
Si thickness consumed, \( X_s = 440\text{Å} \)
CLEAN AND OXIDE GROWTH

OXIDATION SYSTEMS

Microcontroller

Thermocouples (TC’s)

Heat Element

profile TC’s

spike TC’s

Torch

Gas Distribution

Mass flow controllers (MFCs)

Chlorine Source (TCA)

Water Vapor

Bubbler

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Recipe #406

Boat Out    Boat In     Stabilize  Ramp-Up  Soak  Anneal  Ramp-Down
Load  Push  800 °C  800 °C  1100 °C
Pull

25 °C

Interval 0   Interval 1   Interval 2   Interval 3   Interval 4   Interval 5   Interval 6   Interval 7   Interval 8
Any  12 min  15 min  30 min  5 min  65 min  5 min  55 min  15 min
0 lpm  10 lpm  10 lpm  5 lpm  5 lpm  10 lpm  15 lpm  10 lpm  15 lpm
none  N2  N2  N2  O2  O2/H2  N2  N2  N2

At the end of a run the furnace returns to Interval 0 which is set for boat out, 25 °C and no gas flow. The furnace waits in that state until someone aborts the current recipe or loads a new recipe.

Wet Oxide Growth, Target 6,500 Å
WET OXIDE GROWTH CHART

Oxide Thickness in microns

Time in minutes

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Steam
1300C
900C
ROCHESTER INSTITUTE OF TECHNOLOGY
MICROELECTRONIC ENGINEERING

CALCULATION OF OXIDE THICKNESS
Dr. Lynn Fuller

To use this spreadsheet change the values in the white boxes. The rest of the sheet is protected and should not be changed unless you are sure of the consequences. The calculated results are shown in the purple boxes.

### CONSTANTS
- **K**: 1.38E-23 JK
- **(Bo/Ao) dry**: 6230000 μm/hr
- **Ea (dry)**: 2 eV
- **(Bo/Ao) wet**: 89500000 μm/hr
- **Ea (wet)**: 2.05 eV
- **Bo dry**: 7.72E-02 μm/hr
- **Ea (dry)**: 1.23 eV
- **Bo wet**: 2.14E-02 μm/hr
- **Ea (wet)**: 0.71 eV

### VARIABLES
- **Temp**: 1100°C
- **time**: 70 min
- **Xint**: 0 μA

### CHOICES
- 1 = yes, 0 = no

### CALCULATIONS:

\[
Xox (Oxide thickness) = \frac{A}{2}\left[1 - \left(1 + \frac{t}{tau}\right)^{\frac{B}{A}}\right]^{0.5} - 1 = 6435 \text{ Å}
\]

\[
B = \text{Bo exp} \left(\frac{-Ea}{K}\text{Temp}\right)
\]

\[
B/A = (\text{Bo/Ao}) \text{ exp} \left(\frac{-Ea}{K}\text{Temp}\right)
\]

\[
A = 1.64E+00 \text{ μm/μhr}
\]

\[
\text{tau} = (X\text{i2} - AX) / B
\]

**Oxide SiO2**

**Silicon**

Original Silicon Surface Prior to Oxide Growth

0.48 Xox (silicon consumed)
Recipe #270

1000°C

Boat Out  Boat In  Load  Push  Stabilize  Ramp-Up  Soak  Anneal  Ramp-Down  Boat Out
1000°C  800 °C  25 °C  800 °C

Interval 0  Interval 1  Interval 2  Interval 3  Interval 4  Interval 5  Interval 6  Interval 7

Any  12 min  15 min  20 min  93 min  5 min  40 min  15 min  15 min
0 lpm  10 lpm  10 lpm  5 lpm  10 lpm  15 lpm  10 lpm  5 lpm
none  N2  N2  O2  O2/  N2  N2  N2  N2

At the end of a run the furnace returns to Interval 0 which is set for boat out, 25 °C and no gas flow. The furnace waits in that state until someone aborts the current recipe or loads a new recipe.

Dry Oxide Growth, Target 700 Å
What do you get for a 50 minute growth at 1100C?
## Oxide Color Versus Thickness Table

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Color</th>
<th>Thickness</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>Tan</td>
<td>4900</td>
<td>Blue</td>
</tr>
<tr>
<td>700</td>
<td>Brown</td>
<td>5000</td>
<td>Blue Green</td>
</tr>
<tr>
<td>1000</td>
<td>Dark Violet - Red Violet</td>
<td>5200</td>
<td>Green</td>
</tr>
<tr>
<td>1200</td>
<td>Royal Blue</td>
<td>5400</td>
<td>Yellow Green</td>
</tr>
<tr>
<td>1500</td>
<td>Light Blue - Metallic Blue</td>
<td>5600</td>
<td>Green Yellow</td>
</tr>
<tr>
<td>1700</td>
<td>Metallic - very light Yellow Green</td>
<td>5700</td>
<td>Yellow - &quot;Yellowish&quot; (at times appears to be Lt gray or metallic)</td>
</tr>
<tr>
<td>2000</td>
<td>Light Gold or Yellow - Slightly Metallic</td>
<td>5800</td>
<td>Light Orange or Yellow - Pink</td>
</tr>
<tr>
<td>2200</td>
<td>Gold with slight Yellow Orange</td>
<td>6000</td>
<td>Carnation Pink</td>
</tr>
<tr>
<td>2500</td>
<td>Orange - Melon</td>
<td>6300</td>
<td>Violet Red</td>
</tr>
<tr>
<td>2700</td>
<td>Red Violet</td>
<td>6800</td>
<td>&quot;Bluish&quot; (appears violet red, Blue Green, looks grayish)</td>
</tr>
<tr>
<td>3000</td>
<td>Blue - Violet Blue</td>
<td>7200</td>
<td>Blue Green - Green</td>
</tr>
<tr>
<td>3100</td>
<td>Blue</td>
<td>7700</td>
<td>&quot;Yellowish&quot;</td>
</tr>
<tr>
<td>3200</td>
<td>Blue - Blue Green</td>
<td>8000</td>
<td>Orange</td>
</tr>
<tr>
<td>3400</td>
<td>Light Green</td>
<td>8200</td>
<td>Salmon</td>
</tr>
<tr>
<td>3500</td>
<td>Green - Yellow Green</td>
<td>8500</td>
<td>Dull, Light Red Violet</td>
</tr>
<tr>
<td>3600</td>
<td>Yellow Green</td>
<td>8600</td>
<td>Violet</td>
</tr>
<tr>
<td>3700</td>
<td>Yellow</td>
<td>8700</td>
<td>Blue Violet</td>
</tr>
<tr>
<td>3900</td>
<td>Light Orange</td>
<td>8900</td>
<td>Blue</td>
</tr>
<tr>
<td>4100</td>
<td>Carnation Pink</td>
<td>9200</td>
<td>Blue Green</td>
</tr>
<tr>
<td>4200</td>
<td>Violet Red</td>
<td>9500</td>
<td>Dull Yellow Green</td>
</tr>
<tr>
<td>4400</td>
<td>Red Violet</td>
<td>9700</td>
<td>Yellow - &quot;Yellowish&quot;</td>
</tr>
<tr>
<td>4600</td>
<td>Violet</td>
<td>9900</td>
<td>Orange</td>
</tr>
<tr>
<td>4700</td>
<td>Blue Violet</td>
<td>10000</td>
<td>Carnation Pink</td>
</tr>
</tbody>
</table>

To observe a valid color, the wafer must be observed perpendicular to the surface under white (all wavelengths) light, or the optical path length will be different, hence the color will change with the angle.
CLEAN AND OXIDE GROWTH

REFLECTANCE SPECTROMETER
NANOSPEC FILM THICKNESS MEASUREMENT

INCIDENT WHITE LIGHT, THE INTENSITY OF THE REFLECTED LIGHT IS MEASURED VS WAVELENGTH

WHITE LIGHT SOURCE

MONOCHROMATOR & DETECTOR

OPTICS

WAFER

- Oxide on Silicon: 400-30,000 Å
- Nitride: 400-30,000
- Neg Resist: 500-40,000
- Poly on 300-1200 Ox: 400-10,000
- Neg Resist on Ox 300-350: 300-3500
- Nitride on Oxide 300-3500: 300-3500
- Thin Oxide: 100-500
- Thin Nitride: 100-500
- Polyimide: 500-10,000
- Positive Resist: 500-40,000
- Pos Resist on Ox 500-15,000: 4,000-30,000
1. Warm up the furnace to 800°C. 
2. Do a surface particle count on C1. 
3. RCA clean the wafers 
4. Spin Rinse Dry 
5. Do a surface particle count on C1 and C2 
6. Grow Oxide, push, ramp, soak, ramp, pull. 
7. Estimate Oxide Thickness using color chart. 
8. Measure Oxide Thickness
DEFINITIONS

- Surfscan -
- APM -
- HPM -
- Wet O$_2$ -
- Dry O$_2$ -
- Steam -
- Cascade rinser -
- SRD -
- Puller (boat loader) -
- Reflectance Spectrophotometer (Nanospec) -
1. Why do we have to clean the wafers, give at least two reasons.

2. How are the number of particles on the wafer determined (not just the name of the instrument)?

3. List the major steps in the wafer cleaning process and the purpose of each step.

4. Why is oxide growth in wet $O_2$ faster than in dry oxygen?

5. Explain why the color of the oxide changes with its thickness.