Study of particle attachment on silicon wafers during rinsing

*Kurita Water Industries Ltd.*

Takeo Fukui, Koji Nakata
1. Introduction

2. Experimental Method ①

3. Result & Discussion ①

4. Experimental Method ②

5. Result & Discussion ②

6. Conclusion
**Introduction: Requirement for Ultrapure Water Quality**

(ITRS2013 Yield Enhancement Table YE3)

<table>
<thead>
<tr>
<th>Year</th>
<th>Critical particle size [nm]</th>
<th>Number of particles [#/L]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>20</td>
<td>1000</td>
</tr>
<tr>
<td>2014</td>
<td>17.9</td>
<td>1000</td>
</tr>
<tr>
<td>2015</td>
<td>15.9</td>
<td>1000</td>
</tr>
<tr>
<td>2016</td>
<td>14.2</td>
<td>1000</td>
</tr>
<tr>
<td>2017</td>
<td>12.6</td>
<td>1000</td>
</tr>
<tr>
<td>2018</td>
<td>11.3</td>
<td>1000</td>
</tr>
<tr>
<td>2019</td>
<td>10</td>
<td>1000</td>
</tr>
</tbody>
</table>

According to the ITRS, the number of particles should be reduced less than 1000 #/L for the size of at 10 nm particles by the year of 2019.
Introduction: Particle monitoring 1990s to 2019

- **1990s**: DRAM ½ Pitch 500 nm
- **2000s**: 80 nm, 50 nm
- **2019**: 17.0 nm, 20 nm

On-line monitor:
- Red dot > φ 100 nm
- Red dot > φ 50 nm (UDI-50)
- Red dot > φ 20 nm (UDI-20)

It has been reaching the size detection limit of LPC.
According to the ITRS, the number of particles on the wafer should be controlled very severely.
Introduction: Purpose of this study

<Needs for particle in UPW>
- How should we detect the smaller particle?
- How should we reduce the particle in UPW?
- What level should we remove particle in UPW to? ①
- What impurity increases particle adhesion on wafer ②

Focus of this study

Purpose of this study
To clarify how the particle in UPW adsorb onto wafer surface
Experimental Method: Experimental condition and flow

<Experimental condition>
- Wafer: 150 mm SiO₂/Si(100)
- Injected particle: SiO₂
- Injected particle size: around 100 nm
- Particle concentration in UPW: 20,000 #/mL
- Pre-cleaning: O₃ (30ppm) water rinse in 180 sec

Resistivity: >18.0 MΩ·cm
Dissolved Oxygen: <10 ppb

Detect particle size: >0.1 μm
Experimental Method ①: Rinsing recipe

< Rinsing recipe >

<table>
<thead>
<tr>
<th>Operation No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation speed [ rpm ]</td>
<td>500</td>
<td>300</td>
<td>200</td>
<td>ω₁ (1000)</td>
<td>ω₂ (1000)</td>
<td>200</td>
</tr>
<tr>
<td>Time [ sec ]</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>t₁ (20)</td>
<td>t₂ (40)</td>
<td>5</td>
</tr>
</tbody>
</table>

Rinsing process

Drying process (without N2 gas)

The test conditions (ω and t) were changed in order to clarify the behavior of particle adsorption on wafer surface.
Result ①: Effect by the rinsing time on particle adsorption

Rinsing time does not affect the number of particle on wafer.

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<td>Time [sec]</td>
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<td>5</td>
<td>5</td>
<td>$t_1$</td>
<td>40</td>
<td>5</td>
</tr>
</tbody>
</table>

**Graph:**

- Particle in UPW: 20,000#/mL
Result ①: Effect by the rotation speed in rinsing process on particle adsorption

Rotation speed in rinsing process does not affect the number of particle on wafer.

Particle in UPW: 20,000#/mL
Drying time does not affect the number of particles on wafer.
Result ①: Effect by the rotation speed in drying process on particle adsorption

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Particle in UPW: 20,000#/mL

Particle on wafer decreases as rotation speed in drying process increases.
Discussion ①: The model of particle adsorption onto wafer surface

We divided two processes of particle adsorption onto wafer surface. One is rinsing process and another is drying process. We evaluated each of effect.

\[ N = N_{\text{rinse}}(\omega_1) + N_{\text{dry}}(\omega_2) \]
Discussion ①: The model of particle adsorption onto wafer surface

1. In the rinsing process

- Particle adsorption to wafer surface by equilibrium reaction

2. In the drying process

- Particles in the boundary layer accumulate on the wafer surface by water evaporation.
Discussion ①: How to calculate water property

The water thickness and the average velocity of water are shown as the equation (1) and (2).

\[ h = e \frac{r}{(r+l)} \frac{v_0}{v_{av}} \]  \hspace{1cm} (1)

\[ v_{av} = \sqrt{\frac{2(E - \rho ge)}{\rho}} \]  \hspace{1cm} (2)

The boundary thickness (3) can be calculated by the results of equation (1) and (2).

\[ E = \frac{1}{2} \rho v_{av}^2 + \rho ge = \frac{1}{2} \rho v_0^2 + \rho ge + \int_r^{r+l} dE \]

\[ dE = (C_f - F_f) dl = \left( \rho (r+l) \omega^2 - \frac{3 \mu v_{av}}{h^2} \right) dl \]

\[ v(z) = -\frac{3 v_{av}}{2h^2} (z^2 - 2hz) \]  \hspace{1cm} (3)

The number of particles adsorbed on the wafer is calculated.
Discussion ①: Model calculation of spin cleaning

Water thickness and water velocity were calculated as functions of distance from the center of wafer.
Discussion ①: Boundary layer calculation

Boundary layer was calculated as a function of distance from the center of wafer.
Discussion ①: Comparison between the model and experimental result

\[ N = N_{\text{rinse}}(\omega_1) + N_{\text{dry}}(\omega_2) \]

- The calculation result well fitted with experimental result.
- The impact of rinsing process is roughly the same degree as that of drying process and cannot be ignored.

⇒ To avoid adhering particles to wafer on UPW cleaning process, the number of particle in UPW should be decreased.
Experimental Method ②: Experimental condition and flow

<Experimental condition>
- Wafer: 300 mm SiO₂/Si and SiGe(Ge:50%)/Si
- Injected particle: SiO₂
- Injected particle size: 50 nm (for SiO₂/Si), 150 nm (for SiGe/Si)

<table>
<thead>
<tr>
<th>Targeted concentration</th>
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<tr>
<td>H₂O₂</td>
<td>500 ppb</td>
</tr>
<tr>
<td>Urea</td>
<td>100 ppb</td>
</tr>
<tr>
<td>TOC</td>
<td>40 ppb</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.26 mS/m (pH=5.1)</td>
</tr>
<tr>
<td>O₂</td>
<td>900 ppb</td>
</tr>
</tbody>
</table>
Experimental Method ②: Kurita’s water quality control unit

1. House UPW In
2. O₂ Gas Dissolving Membrane
3. Urea Remover (Bio Activated Carbon)
4. Particle Filter - 0.45um (Post BAC Filter)
5. Ion Exchange Resin
6. UV Exposure
7. H₂O₂ Remover
8. Heat Exchanger
9. Degasifier Membrane
10. Ion Exchange Resin
11. Gas Dissolving Membrane
12. Final Filter #1 (10nm)
13. Final Filter #2 (10nm)
14. Contaminant Solution and Injection Pump
15. Nanoparticle Solution and Injection Pump
16. Kurita UPW Output
Result & Discussion ②: Effect of chemicals on SiO$_2$/Si wafer and SiO$_2$ particle

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CO$_2$ has the influence on particle adhesion to SiO$_2$ surface.
Result & Discussion ②: Effect of chemicals on SiGe/Si wafer and SiO₂ particle

**Targeted concentration**

<table>
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<tr>
<th>Chemical</th>
<th>Targeted concentration</th>
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<tbody>
<tr>
<td>H₂O₂</td>
<td>500ppb</td>
</tr>
<tr>
<td>Urea</td>
<td>100ppb</td>
</tr>
<tr>
<td>TOC</td>
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<td>O₂</td>
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**CO₂ has the influence on particle adhesion to SiGe surface.**
CO₂ has a strong influence on the number of particle on wafer.
Result & Discussion②: Relationship between zeta potential and pH

In CO₂ water, the zeta potential of SiO₂ approaches zero, resulting in the drop of the repulsive force between the wafer and particles.

⇒ We would like to discuss the effect of the surface charge by changing particle species in the next study.
Conclusion

We studied about the particle adhesion to wafer and the impact of impurity.

(1) The rotation speed of drying process is one of the most effective parameters in the particle adsorption.

(2) The number of particles adsorbed at the rinsing process is large and almost constant.

(3) CO$_2$ has the influence on particle adhesion to SiGe and SiO$_2$ surface to wafer.

Next, we would like to investigate the effect of the surface charge and the particle size in detail.
We can support quality stabilization of a semiconductor products.

Not just water, Creativity

Thank you for your attention

KURITA WATER INDUSTRIES LTD.