CO₂-Dissolved Water Cleans for 2xnm-Node Silicon Devices in a Single Wafer Megasonic System
Chan Geun PARK and HongSeong Sohn
Akrion Systems LLC., 6330 Hedgewood Drive, Suite #150, Allentown, PA 18106, USA

Keywords: Megasonic clean, CO₂-Dissolved Water, Particle removal efficiency, Pattern collapse

Introduction
Megasonic cleans have been applied to remove defects such as particles and polymer/resist residues in silicon wafer fabrication of IC devices. However, with the shrink of device technology node, megasonic cleans are being challenged to maintain high cleaning efficiency promoted by streaming force of stable cavitation for the smaller particles without producing pattern collapse caused by violent implosions of transient cavities [1]. S. Kumari et al. reported that CO₂-dissolved water (CO₂ DIW) was potentially able to suppress wafer damage during megasonic exposure by minimizing unrestrained explosion of transient cavities. This is accomplished through the study on Sonoluminescence (SL), the phenomenon of release of light when liquid is irradiated by sound wafers of sufficient intensity, as a sensitive indicator of cavitation events [2, 3]. This paper compares the effects of CO₂ dissolution on particle removal efficiency (PRE) and pattern collapse in a range of megasonic power with >100nm-size Si₃N₄ particles and 2xnm node line/space-pattern, respectively to N₂-gasified water (N₂ DIW).

Experimental
Experiments were performed on a 300mm Akrion Systems’ Goldfinger® Velocity™ tool, which provides two different types of megasonic cleans; Front Side (FS) megasonic systems with a quartz rod connected to piezoelectric crystal (1.6MHz) and Back Side (BS) with a plastic-covered piezoelectric material (830kHz), as shown in Figure 1. CO₂ (approx. 1000ppm) DIW and N₂ (approx. 20ppm) DIW were prepared using each membrane continuously filled with CO₂ or N₂ at a certain pressure. For the particle removal experiments, 300mm bare silicon wafers were contaminated with Si₃N₄ particles (>100nm in diameter and around 20,000 particles per wafer). Number of particles on the wafer was counted from 100nm-size by SP1 (KLA-Tencor) before/after contamination and after cleans. Pattern collapse evaluations were conducted on two different kinds of multi-stacked gate poly structures; 25nm-width with 9:1 aspect ratio (AR) and 35nm-width with 10:1 AR.

Results and Discussion
PRE for Si₃N₄ particles was compared between CO₂ DIW (RT) and N₂ DIW (RT) in 0~50W range of FS and BS Meg power as shown in Figure 2. Goldfinger® BS Meg can remove particles from both the front and back sides at the same time with sufficiently high PRE as FS Meg does for front side only. CO₂ DIW showed >50% lower PRE than N₂ DIW that would be related to the ability of CO₂ to quench SL generation in DIW exposed to megasonic radiation [3]. Acidity of CO₂ DIW would be one of the reasons for lower PRE of CO₂ DIW; however, spiking diluted ammonia water (1:800 =30% NH₄OH:DIW) to the CO₂ DIW (no change on CO₂ concentration) puddle on the wafer surface during megasonic radiation provides comparable PRE to N₂ DIW.

Pattern collapse was compared between CO₂ DIW and N₂ DIW with 25nm-width (AR=9:1) gate poly wafers in 0~50W range of FS or BS power. As shown in Error! Reference source not found., pattern collapse was greatly improved by CO₂ dissolution with zero collapse at 30W Meg power, which has >40% PRE. Wafer damage was evaluated again on a 34nm-width (AR=10:1) gate poly pattern in order to see any loss by pattern collapse when using diluted NH₄OH spikes to improve the
PRE of CO₂ DIW. According to Table 1, wafer damage was not found even at 40W BS Meg power at which >85% Si₃N₄ particles are removed from the silicon surface. The results indicate that CO₂ suppresses pattern collapse in DIW, and is also able to inhibit wafer damage in the presence of other gases that may cause pattern collapse.

References

Figure 1: Goldfinger® FS and BS Megasonic systems and their schematic diagrams of the sound transmission path
Figure 2: PRE of CO$_2$ DIW (with/without NH$_4$OH Spike) and N$_2$ DIW as functions of FS and BS Meg power

Figure 3: Full wafer scan results for pattern collapse comparison between N$_2$ DIW and CO$_2$ DIW as a function of Meg power @ 25nm (with 9:1 aspect ratio) gate poly structure

Table 1: Full wafer scan results of pattern collapse on 35nm (with 10:1 aspect ratio) gate poly structure and PRE (>100nm Si$_3$N$_4$) after CO$_2$ DIW clean with NH$_4$OH spike as function of BS Meg power

<table>
<thead>
<tr>
<th>Split</th>
<th>Process Condition</th>
<th>Pattern Collapse</th>
<th>Expected PRE (@ ≥100 nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BS Meg 30W 30 sec with NH$_4$OH spike</td>
<td>No Damage</td>
<td>75%</td>
</tr>
<tr>
<td>2</td>
<td>BS Meg 35W 30 sec with NH$_4$OH spike</td>
<td>No Damage</td>
<td>80%</td>
</tr>
<tr>
<td>3</td>
<td>BS Meg 40W 30 sec with NH$_4$OH spike</td>
<td>No Damage</td>
<td>85%</td>
</tr>
</tbody>
</table>