Defect Testing Using an Immersion Exposure System to Apply Immediate Pre-Exposure and Post-Exposure Water Soaks

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ABSTRACT

The rapid expansion in the number of semiconductor manufactures using immersion imaging systems confirms the acceptance of immersion lithography for critical layer imaging. One of the early concerns in the development of immersion lithography was defect levels. These defects levels have been dramatically reduced with each new system, and are now approaching defect levels similar to dry systems. Continued reduction of defects will be required as smaller critical dimensions are pursued on immersion systems with NAs well over one. In this work have studied new ways to further reduce the number of defects. For this investigation an ASML 1150i α-immersion scanner was used for both ultra pure water soaking and for image exposure. Previous pre-exposure and post-exposure rinse/soak tests have been conducted on coater/developer tracks; however using the track causes a significant time delay from soak to exposure, and vice-versa. For this experimentation a dynamic soak of coated wafers immediately before exposure and immediately after exposure was performed on the immersion scanner with controlled soak times. The wafers were then processed as normal on a TEL-Lithius coater/developer track. Defect type and size were analyzed to determine the interactions which reduced defects. The findings showed that an immediate pre-exposure soak of 14 seconds reduced image expansion defects by 38%, compared to no pre-exposure soak. Test results also indicated that the most frequent defect, bridging, was not produced by water droplets.

Keywords: lithography; immersion; defects; pre-soak; post-soak; bridging; expansion, water

1. INTRODUCTION

In immersion lithography, the use of a pre-exposure rinse/soak (pre-soak) and a post-exposure rinse/soak (post-soak) to reduce pattern expansion and particle defects for various resist stacks is well known [1]. The pre-soaks and post-soaks produce no significant change in CD line width [3,4]. Also wafer track manufactures now produce tracks with dedicated pre-soak and post-soak modules to reduce immersion defectivity [5]. Our interest centered on the feasibility and effect of using the immersion scanner to perform an immediate pre-exposure and/or post-exposure soak, thereby eliminating the up to 30 second track soak to exposure delay.
2. EXPERIMENTAL SETUP

The experiments were carried out on an ASML 1150i alpha-immersion scanner clustered with a TEL Lithius track. All of the resist stack coating materials: BARC; photoresist; and topcoat; were installed in the TEL Lithius track. Using a TOPCON Wafer Analyzer WM-5000, bare 300mm Si wafers were measured and those wafers with initial defect counts of less than 25 particles per wafer were selected for these experiments. For each test condition an 110nm line-space grating was exposed at best dose and focus. Two scan speeds were also used, normal and 20% of normal.

Immediate pre-soak and post soak wetting was performed on the alpha-immersion scanner by placing zero dose edge fields before and after standard fields in the exposure layout, as shown below:

Figure 1. Exposure field layout for standard and pre/post soak edge fields.

For pre-soak the immersion hood on the alpha-immersion scanner moves horizontally back and forth across the wafer to each zero dose edge field, wetting the entire exposure area of the wafer and then immediately begins the standard exposure of wafer. Post soak was accomplished in a similar method, with the movement order of the zero dose edge fields coming immediately after the standard exposure. Immediate pre-soak with standard exposure and followed by an immediate post soak was also performed.

After the exposure and soak process was finished in the 1150i, all wafers were PEB and Develop process normally on the TEL Lithius track. Defect inspection was conducted on the AMAT ComPlus MP with an 8mm edge exclusion; and defect review was performed on an AMAT SEMVision. Contact angle measurements were made on the Data Physics FDS Contact Angle System OCA.
3. INITIAL SOAK TESTING

<table>
<thead>
<tr>
<th>Wafer Slot #</th>
<th>Process</th>
<th>Soak Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Standard</td>
<td>none</td>
</tr>
<tr>
<td>2</td>
<td>Pre-soak</td>
<td>14 sec</td>
</tr>
<tr>
<td>3</td>
<td>Post-soak</td>
<td>14 sec</td>
</tr>
<tr>
<td>4</td>
<td>Pre &amp; Post soak</td>
<td>14 sec each</td>
</tr>
<tr>
<td>5</td>
<td>Pre-soak</td>
<td>171 sec</td>
</tr>
<tr>
<td>6</td>
<td>Standard</td>
<td>none</td>
</tr>
<tr>
<td>7</td>
<td>Pre &amp; Post soak</td>
<td>14 sec each</td>
</tr>
<tr>
<td>8</td>
<td>Post-soak</td>
<td>14 sec</td>
</tr>
<tr>
<td>9</td>
<td>Pre-soak</td>
<td>14 sec</td>
</tr>
<tr>
<td>10</td>
<td>Pre-soak</td>
<td>171 sec</td>
</tr>
<tr>
<td>11</td>
<td>Standard</td>
<td>none</td>
</tr>
<tr>
<td>12</td>
<td>Post-soak</td>
<td>14 sec</td>
</tr>
<tr>
<td>13</td>
<td>Pre-soak</td>
<td>171 sec</td>
</tr>
<tr>
<td>14</td>
<td>Pre-soak</td>
<td>14 sec</td>
</tr>
<tr>
<td>15</td>
<td>Pre &amp; Post soak</td>
<td>14 sec each</td>
</tr>
<tr>
<td>16</td>
<td>Standard</td>
<td>none</td>
</tr>
<tr>
<td>17</td>
<td>Pre-soak</td>
<td>171 sec</td>
</tr>
<tr>
<td>18</td>
<td>Post-soak</td>
<td>14 sec</td>
</tr>
<tr>
<td>19</td>
<td>Pre &amp; Post soak</td>
<td>14 sec each</td>
</tr>
<tr>
<td>20</td>
<td>Pre-soak</td>
<td>14 sec</td>
</tr>
</tbody>
</table>

Figure 2. Twenty wafers were coated and processed as shown.

Due to the small sample size of only 4 wafers per test run, and high standard deviation per test condition, the results from the initial testing were used to indicate trends. The trend in the data showed that test condition of 14 second pre-soaked had a lower number of total patterned defects, as seen in Figure 3. In-depth testing using a large sample size was then conducted on the 14 second pre-soak and standard process.

Figure 3. Initial test results chart with tests normalized to the standard process.
3. PRE-SOAK TEST

Twenty wafers were coated in-line with every other wafer pre-soak processed. As seen in the figure 4 and 5, all of the major defect types were obtained for both standard and pre-soak processes.

As shown in Figure 5, 60% of all defects were bridging. Looking at just the bridging defects, 99% of all bridging defects are composed of the single, double, and triple bridging defects pictured above. Surprisingly the single bridge defect was not the most common bridge type. The double bridge at 65% had more than two times the number of single bridge defects:

- **Single Bridge Defects**: Mean = 25%, Sigma = 7%
- **Double Bridge Defects**: Mean = 65%, Sigma = 8%
- **Triple Bridge Defects**: Mean = 9%, Sigma = 2%

Figure 4. Pictures of major defects types.
Unfortunately the pre-soak results showed no significant effect on the most numerous defect, bridging. Only the immersion specific defect pattern expansion showed a significant effect with a pre-soak, as shown for all 20 wafers in Figure 6.

Figure 6. Chart of standard and pre-soak pattern expansion defect percent for all 20 wafers.
Pattern Expansion Defect Statistical Summary

Student's \( t \)-Test: results at 0.05 alpha

\[ t = 2.10, \quad t_{\text{calculated}} = 4.08, \quad \text{degrees of freedom} = 18 \]

The probability of the null hypothesis:

\[ \text{Pre-soak Process Expansion Defects} = \text{Standard Process Expansion Defects} \]

is rejected, thusly the results are significantly different at 95% confidence.

6. CONTACT ANGLE MEASUREMENT

Contact angle measurements were made to verify that the reduction in pattern expansion defects was not coming from a pre-soak induced change in hydrophobicity of the resist stack topcoat.

The contact angle on full stack coated wafer was measured on the Data Physics FDS Contact Angle System OCA at a tilt of zero, 45 degrees and 90 degrees. This same wafer was then soaked with UPW water for 1 minute and the same contact angle tilt measurements made. The results showed no significant changes in surface hydrophobicity.
5. BRIDGING & PRE-SOAK TEST AT SLOW SPEED

To test if bridging defects are formed by water droplets, the pre-soak and standard defect test was repeated but at a 20% normal scan speed. Due to known water meniscus stability issues with the 1150i alpha-immersion scanner, slowing the stage speed to 20% eliminates nearly all water escaping the immersion hood [6]. Therefore by slowing the stage speed, one would expect fewer water droplets left on the wafer, yielding fewer expansion defects. Also if bridging defects are just small expansion defects caused by smaller water droplets on the wafer, then the total number of bridging defects should also be reduced compared to normal speed.

Ten standard and pre-soak wafers were alternately exposed in the alpha-immersion scanner at the slow 20% of normal stage speed. These wafers were processed identically on the inline TEL Lithius track. As expected on the 1150i at slow speed, a very stable water meniscus in the immersion hood produced less water droplets on the wafer, resulting in a reduction in the percent of pattern expansion defects compared to normal speed.

<table>
<thead>
<tr>
<th></th>
<th>Standard Process</th>
<th>Pre-Soak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patterned Expansion Defects at Normal Speed</td>
<td>11.2%</td>
<td>6.9%</td>
</tr>
<tr>
<td>Patterned Expansion Defects 20% of Normal Speed</td>
<td>3.2%</td>
<td>1.4%</td>
</tr>
</tbody>
</table>

The total bridge defect counts did not decrease at slow speed; but showed an increase compared to normal speed. At slow speed the percent of bridging defects increased from 60% to 87% of the total defects, shown in Figure 8. As the number of bridging defects did not decrease with a decrease in water droplets on the wafer, we may infer for this study and resist stack, that water droplets were not the cause of bridging defects.

![Averaged Pattern Defects at 20% Normal Stage Speed](image)

Figure 8. Chart of averaged defect type vs. percent of total defects at 20% of normal stage speed
5. SUMMARY

1. Bridging defects were shown to be the most prevalent patterned defect but soaking showed no effect on these defects. Slow speed testing did show a reduction in water droplet expansion defects but no change in bridging defects, indicating for this resist stack, that water droplets do not cause bridging. Future testing will be conducted on different resist stacks to collaborate the lack of effect of water droplets on bridging. Also two other hypothesis on bridge formation, particle induced and residual resist polymer induced will be investigated.

2. The immediate soak showed similar reductions in pattern expansion defects as previously reported on pre-exposure soak and post-exposure soak performed on the track/coater. For the resist stack tested in this paper, an immediate pre-soak showed a 38% reduction in pattern expansion defects. The reduction in pattern expansion defects with an immediate pre-soak was also observed at slow stage speeds.

3. Contact angle measurements from pre and post-soak showed no significant change, suggesting that there is no significant change in immersion hood water meniscus stability. Therefore the reduction in expansion defects may be explained by the reduced impact of water droplets on a more water concentrated topcoat.

4. These results demonstrated a viable method for immediate soak processing. Future testing will be conducted on an ASML 1700i production tool; and will combine immediate soaks with pre & post-soak treatments on the track to determine the optimal delay time between soak and exposure. Future testing should also include an automated defect classification tool.

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