Infinite Etching Selectivity with Conventional Photoresist in a Bosch Process

Chang, Bingdong; Leussink, Pele; Jensen, Flemming; Hübner, Jörg; Jansen, Henri

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Deep reactive ion etching (DRIE) has become a standard technology to transfer patterns directionally into silicon, but to achieve high aspect ratios remains challenging. By performing a pulsed process (e.g. a Bosch sequence), the sidewall of trenches can be protected during an etch process and the etch depth can be significantly improved. However, when etch depth increases, the silicon etch rate is limited by RIE lag [1], while the mask is consumed with an almost constant rate. This means that the selectivity (etch rate of silicon divided by etch rate of mask) drops drastically when aspect ratio increases and in the end, masks will be totally eroded away. This issue sets a limit for high aspect ratio etching and a lot of efforts have been invested to find a “hard” mask with a high selectivity, e.g. Cr, SiO$_2$, Al$_2$O$_3$, etc. [2]. However, a hard mask can be sputtered during etching and creates roughness. Furthermore, the transfer of resist patterns into the hard mask will increase fabrication complexity.

Here we report a reproducible method to achieve an infinite etching selectivity with a conventional DUV photoresist (JSR KRF M230Y). Etching was performed with a Pegasus DRIE tool (SPTS). Passivation time was kept to be 1.5s, while etching time was carefully tuned using the parameter ramping feature, so that the scallop sizes are almost the same along the trench for different numbers of cycles, other parameters we used are shown in table 1. Etching profiles were inspected with SEM.

Table 1. DRIE parameters.

<table>
<thead>
<tr>
<th>Gas flow (scm)</th>
<th>CF$_4$</th>
<th>SF$_6$</th>
<th>Ar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passivation 1.5s</td>
<td>300</td>
<td>5</td>
<td>600</td>
</tr>
<tr>
<td>Etching 3.5s</td>
<td></td>
<td></td>
<td>250</td>
</tr>
<tr>
<td>Generators (W)</td>
<td>Coil</td>
<td>3000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Platen</td>
<td>1</td>
<td>75</td>
</tr>
</tbody>
</table>

To demonstrate this extraordinary ability, wafers were prepared with 65µm bottom anti-reflective coating (BARC) and 300nm conventional DUV resist and patterned by DUV stepper lithography with 1 micron sized features. After etching the BARC layer, 50 cycles were performed to reach an etch depth of 18.8µm (Fig.2.a), while the resist remained intact (Fig.2.a). After 100 cycles, the etch depth was doubled and the resist still undisturbed (Fig.2.b). Noticeably, a FC layer starts to develop covering the topside of the etching structure making the trench opening smaller (Fig.3.b). When we increased the number of cycles further to 150, the etching depth was around 58.1µm, which implied a high aspect ratio of more than 50, while the sidewall of the trench started to be corroded (Fig.2.c).

In conclusion, by carefully tuning a pulsed process, silicon can be etched directionally with infinite selectivity towards conventional photoresists; i.e. resist is not consumed at all. Obviously any mask (e.g. Cr, SiO$_2$ or Si$_3$N$_4$), even though not demonstrated here, will be able to perform this task as well. The process is believed to be the key to realize ultrahigh aspect ratio structures with ordinary masking.

Keywords: Silicon plasma etching, infinite selectivity, Bosch sequence

References: