Fullerene derivative based spin-on-carbon hard masks for advanced lithographic applications

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Fullerene Derivative Based Spin-on-Carbon Hard Masks for Advanced Lithographic Applications

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Introduction
The advance of lithographic resolution requires extremely thin photoresist films for the fabrication of 1x nm structures to mitigate resist collapse during development, but the use of such thin films will limit achievable etch depths.

Key hard mask properties
Key attributes for hard mask materials are:
- Cost
- Spin coating from standard solvents
- Short bake durations
- High thermal stability
- Low etch rate in halogen plasmas
- High etch rate in oxygen plasmas
- High resolution patterning (20 nm or better)
- Low “wiggle” at sub-30 nm

Distortion, (“wigging”) of the features in the thick carbon layer during the final fluorne silicon etch step:
- can be a significant problem at smaller feature sizes.

The etch resistance of the fullerene based material allows high-aspect ratio plasma etching from a very thin film and at high-resolution.

The materials have low levels of aliphatic hydrogen, which is proposed as a solution to the “wigging” of features below 30nm during the plasma etch step to transfer of the features to the underlying layer.
- Wigging is not observed with IM hard mask materials.

Mechanical Characterization
Measurements of surface roughness and mechanical characteristics performed by AFM and nanoindentation.

<table>
<thead>
<tr>
<th>Material</th>
<th>Bare Silicon</th>
<th>IM-HM-110</th>
<th>IM-HM-120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Roughness</td>
<td>0.28 nm</td>
<td>0.36 nm</td>
<td>0.28 nm</td>
</tr>
<tr>
<td>RMS Roughness</td>
<td>0.35 nm</td>
<td>0.45 nm</td>
<td>0.36 nm</td>
</tr>
<tr>
<td>Peak to Valley</td>
<td>4.57 nm</td>
<td>4.51 nm</td>
<td>3.12 nm</td>
</tr>
<tr>
<td>Young’s Modulus</td>
<td>130 – 170 GPa</td>
<td>5 – 6 GPa</td>
<td>4.7 GPa</td>
</tr>
<tr>
<td>Hardness</td>
<td>8.7 GPa</td>
<td>800 MPa</td>
<td>1.15 GPa</td>
</tr>
</tbody>
</table>

Fullerene Derivatives
A range of fullerene derivatives have been investigated for etch behavior. Etch tests on 10 μm patterned strips have been performed to measure the etch rates in silicon etching, compared to a control resist.

<table>
<thead>
<tr>
<th>Hard Mask Formulation</th>
<th>Carbon Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>IM-110</td>
<td>86.7%</td>
</tr>
<tr>
<td>IM-120</td>
<td>85.0%</td>
</tr>
<tr>
<td>IM-130</td>
<td>83.7%</td>
</tr>
<tr>
<td>IM-140</td>
<td>83.7%</td>
</tr>
</tbody>
</table>

Contrary to expectation as the carbon content is decreased (Omnih number is increased), the etch resistance has increased.

Pattern Transfer I
The material is capable of high-resolution patterning. Sparse line features with a width of 20 nm were successfully etched into silicon as well as 30 nm dense patterns as shown for two of the materials.

Pattern Transfer II
Using the extreme ultraviolet interference lithography tool at PSI, Switzerland, an HSG resist layer was patterned on top of the hard mask stack to produce dense 25 nm half pitch and 12 nm semi dense patterns.

Summary and Outlook
The use of multilayer hard masks is now essential for the semiconductor industry to produce devices at ever shrinking dimensions, particularly given recent developments in three dimensional device architectures, such as FinFET and Intel tri-gate devices.

These fullerene based hard mask materials outperform existing state of the art materials across several critical performance metrics, whilst maintaining the advantages of spin-on materials over CVD deposited carbon.

New formulations under development offer:
- further improved thermal stability
- increased etch resistance
- alternative casting solvents

The Irresistible Materials HD-140 hard mask formulation is currently available from MicroChem, a US based supplier of specialist chemicals for microelectrographic applications (via a non-exclusive license agreement).

Acknowledgements