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

Conference or Workshop Item

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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, ("wiggling") of the features in the thick carbon layer during the final fluorine 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 "wiggling" of features below 30nm during the plasma etch step to transfer of the features to the underlying layer.

- Wiggling 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></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>

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

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>96.7%</td>
</tr>
<tr>
<td>IM-120</td>
<td>94.5%</td>
</tr>
<tr>
<td>IM-130</td>
<td>92.0%</td>
</tr>
<tr>
<td>IM-140</td>
<td>83.7%</td>
</tr>
</tbody>
</table>

The performance of the material does not suffer as a result of the cost reduction measures.

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 trigate 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 HM-140 hard mask formulation is currently available from MicroChem, a US based supplier of specialist chemicals for micro lithographic applications (via a non-exclusive license agreement).

Acknowledgements

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