Spin-on-carbon hard masks utilising fullerene derivatives

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Version: Not Set

Link(s) to article on publisher’s website:
http://dx.doi.org/doi:10.1117/12.2219212
http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=2508811

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Spin-on-Carbon Hard Masks utilising Fullerene Derivatives

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Introduction

The advance of lithographic resolution requires extremely thin photoresists 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.

Pattern collapse due to aspect ratio

Multilayer hard mask stacks are a possible solution. We have developed a fullerene based spin-on carbon hard mask material, capable of high aspect ratio etching.

Process flow of tri-layer scheme

The high resolution image is captured in a thin resist top coat layer and transferred down through the stack to produce high aspect ratio carbon hard mask structures suitable for substrate etching.

HM140-350-100 performance

Results of independent etch trials at IMEC

The HM140-350 series formulations use a low cost to produce mixed fullerene multi-adduct derivative, which gives no degradation in the performance as a result of the cost reduction measures.

Spin on 20 nm hard mask features in HM140-350-000

30 nm half pitch patterns in HM1140-350-000

Roughness Characterization

Measurements of surface roughness performed by AFM

Bare silicon HM240-383-010 50 nm film thickness HM340-383-010 250 nm film thickness

<table>
<thead>
<tr>
<th>Roughness</th>
<th>HM240-383-010 50 nm</th>
<th>HM340-383-010 250 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Roughness</td>
<td>0.070 nm</td>
<td>0.337 nm</td>
</tr>
<tr>
<td>RMS Roughness</td>
<td>0.094 nm</td>
<td>0.422 nm</td>
</tr>
<tr>
<td>Peak to Valley</td>
<td>2.637 nm</td>
<td>3.294 nm</td>
</tr>
</tbody>
</table>
| Roughness figure for 50 and 250nm thick films are similar, with slightly better results for the thicker film.

Key hard mask properties

Key attributes for hard mask materials include:
- Spin coating from standard solvents
- High thermal stability
- Low etch rate in halogen plasmas
- High etch rate in oxygen plasmas
- High resolution patterning (20 nm or better)
- Low "wiggles" at sub-30 nm

The etch resistance of the Irresistible Materials’ 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.

New HM340 Hard Mask

Combining the increased thermal stability and etch resistance of the new 300 series, with increased fullerene to crosslinker ratio.

The material spins from the more acceptable anisole casting solvent. High solubility, >250 g/l allows for a wide range of spun film thickness

Spin on 25 nm half pitch 612 nm semi-dense patterns etched into silicon

HM100 series fullerene hard mask

Previously reported good results for the HM100 series:
- Cyclohexanone casting solvent.
- Material available from MicroChem.

Key performance measures:
- Film thickness vs. spin speed curves for HM140-350-000 series

Very good etch performance has been demonstrated by researchers at McGill University, Montreal.

Tests at IMEC show HM140-350-100:
- More etch resistant than "standard" SoC for the etching amorphous-Si, SiN and SOG
- Has an etch performance approaching amorphous carbon (see below).

Improved thermal stability

Prolonged etch with temperature
- 250 nm spun films, baked in N2 for 5 minutes

TGA (manually spread film to increase mass for analysis)

The new HM340-383-010, with a higher content of the more thermally stable fullerene derivative and a slightly higher crosslinking bake temperature, has shown improved thermal stability, both in terms of thickness loss with temperature and mass loss with temperature.

Etch Performance

From the etch performance data, the HM300 series was shown to give better etch performance than the HM100 series, and the HM340 is predicted to have a significantly better etch performance than the HM140.

Normalised etch rate - iso-carbon variants

With the further increased carbon content (from 88.4% to 95.3%), the etch resistance of the HM340-383-010 is expected to be very good. This will be verified in upcoming etch trials.

Summary and Outlook

The use of multilayer etch stacks incorporating carbon hard masks is now essential to enable the semiconductor industry to produce devices at ever shrinking dimensions, particularly given recent developments in these dimensional device architectures, such as FinFET and trigate devices.

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

The new HM340-383-010 has a high thermal stability and a very high carbon content, offering high etch resistance.

IM hard mask materials are available from MicroChem, a supplier of specialist chemicals for microlithographic applications (via a non-exclusive license agreement).

Acknowledgements