Novel Spin-on Carbon Hardmasks

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1. Introduction

Irresistible Materials Ltd. (IM), a spin out company from the University of Birmingham, is **developing novel fullerene materials to enable the next generation of silicon microchips.**

Spin-on carbon (SOC) hardmasks are an increasingly key component of the micro-chip fabrication process. They are frequently used to improve the resists' selectivity to silicon during plasma etching. Furthermore, as chip architectures become increasingly complex the use of hardmasks to improve the aspect ratio of features in silicon is critical. In this context, the 'aspect ratio' is the ratio between the height of a feature on a silicon wafer and its width. For many emerging multi-layer chip architectures, such as tri-layer etch-stacks, a large height to width ratio is required to maintain small lateral features across multiple vertical layers (figure 1).

In a tri-layer etch stack the bottom layer is typically thick amorphous carbon deposited by chemical vapor deposition (CVD). The challenges for CVD are high capital and running costs, particle defects, and the non-planarizing nature of the layer. Irresistible Materials' innovative SOC materials are based on novel carbon fullerene derivatives (CFDs). These outperform CVD and existing state-of-the-art materials across several critical performance metrics (refer to data sheet overleaf).

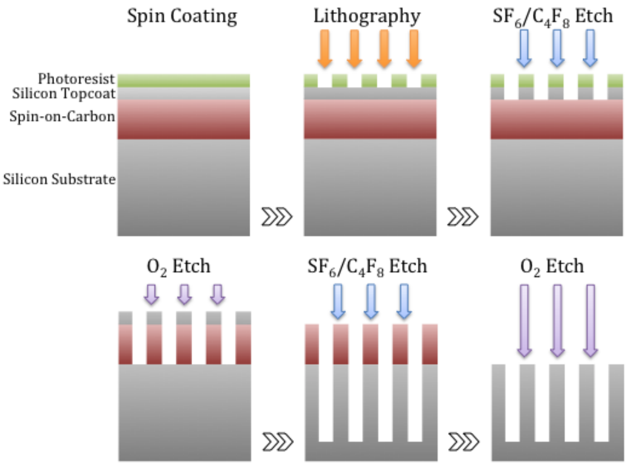

Figure 1: A typical tri-layer etch stack process showing the amplification of achievable aspect ratio.

Irresistible Materials has demonstrated 20nm pattern transfer at aspect ratios of 10:1. Development work continues with our academic and industrial partners (including the University of Birmingham and Nano-C, Inc.), with a goal of optimizing the existing materials to achieve sub-20 nm patterns with aspect ratios significantly greater than 20:1. These novel CFD SOCs will lead to reduced energy consumption in manufacture (replacing energy intensive CVD), but more importantly will enable high efficiency FinFET/Trigate architectures and thus low power consumption in computing.

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2. Industry, Problems & IM's Solution

The current spin-on approach is to use aromatic polymers for the SOC together with a silicon rich spin-on-glass to form the bottom two layers of the stack. For instance a Novolac: Hydrogen Silsesquioxane bilayer has achieved 40 nm half-pitch with an aspect ratio of 3.25:1 and isolated 40 nm lines with an aspect ratio of 20:1. However, distortion, ("wiggling") of the features in the thick carbon layer during the final fluorine silicon etch step, is a significant problem at smaller feature sizes. It is believed that the aliphatic hydrocarbon content of SOCs, and particularly the presence of hydrogen, is responsible for this unwanted effect, and there has been a drive towards even more aromatic polymers based on e.g. polycyclic aromatics such as naphthalene and anthracene. **Irresistible Materials' Carbon Fullerene Derivatives address this issue.**

By their nature CFD have extremely low hydrogen:carbon ratio, exceeding even polycyclic aromatic polymers. Indeed, Irresistible Materials' SOC hardmask is uniquely suited to this task due to the CFD's high etch durability in fluorine based ICP plasma etching. This is derived from their high carbon content. In addition, they have high temperature stability (see data sheet overleaf). As performance testing and optimization progresses, the core material is being refined to increase the total and the aromatic carbon contents even further.

3. Corporate Overview

Irresistible Materials owns an exclusive license to the University of Birmingham fullerene photo-resist and SOC patent portfolio covering a broad range of intellectual property. We continue to work closely with the University of Birmingham as the SOC hardmask, as well as the novel EUV and e-beam resist materials are advanced through to commercial use. Irresistible Materials has also entered an alliance with Nano-C for the supply of CFD materials. Nano-C is a world leading fullerene manufacturer, enabling high volume, high quality production at commercially attractive pricing.

4. Summary

The use of multilayer hardmasks is now essential for the semiconductor industry to produce devices at ever shrinking dimensions, particularly given recent developments in device architecture, such as FinFET and Intel trigate devices. Irresistible Materials' novel SOC materials enable increased aspect ratio 3D device architectures. Indeed, Irresistible Materials' high resolution, high aspect ratio SOC hardmasks will not only benefit semiconductors, they hold the potential to boost nanofabrication capabilities across many markets and applications.

Irresistible Materials' SOC latest hardmask material is now available for trial from MicroChem, www.microchem.com.

Spin-on-Carbon Hardmask Data Sheet

Variant: IM-HM-140			
Etching (ICP, SF_6/C_4F_8)	Selectivity to Silicon Etch Rate (nm/s) Etching Technique *Control Resist* *Control Etch Rate*	1 : 9 0.82 nm/s ICP mixed mode etching *SAL601* *1.65 nm/s*	
Etching (ICP, SF_6/CHF_3)	Selectivity to Silicon Etch Rate (nm/s) Etching Technique *Control Resist* *Control Etch Rate*	1 : 12 0.84 nm/s ICP mixed mode etching *SAL601* *1.7 nm/s*	
Solvent Compatibility (Coating)	Casting Solvent Castable Thickness Other solvent options available	Cyclohexanone 30- 500 nm	
Solvent Compatibility (Elution after hardening)	Thickness Loss (PGME, PGMEA) Thickness Loss (Ethyl Lactate) Thickness Loss (Anisole) Thickness Loss (MCB) Thickness Loss (Cyclohexanone) Thickness Loss (TMAH 25%)	No dissolution after 1 min immersion No dissolution after 1 min immersion No dissolution after 1 min immersion No dissolution after 1 min immersion No dissolution after 1 min immersion No dissolution after 1 min immersion	
Thermal Characteristics (under N_2)	Thickness Loss	Thickness Loss (%) @ 300°C Thickness Loss (%) @ 350°C Thickness Loss (%) @ 400°C	0.8% after 5 min 4.4% after 5 min 12.6% after 5 min
	Mass Loss (TGA)	Mass Loss (%) @ 300°C Mass Loss (%) @ 350°C Mass Loss (%) @ 400°C	3.0% 6.0% 13.7%
Images ***Left:*** ***30 nm lines transferred into fullerene hardmask*** ***Right:*** ***22 nm lines etched into silicon***