Fluorocarbon-based Atomic Layer Etching of Silicon Dioxide in conventional plasma tools

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Controlling Ångstrom-thick film etching is essential for further development of sub-10 nanometer semiconductor manufacturing. The atomic scale era requires the use of decreasing film thickness together with stringent surface property control: preventing material damage and controlling over etching directionality and material selectivity.[1]

Single digit nanofabrication requires the ability to achieve atomic scale etching control and material selectivity during pattern transfer. Atomic Layer Etching (ALE) satisfies these needs as critical dimensions continue to shrike. An ALE process consists of two sequential steps: A) surface modification: a thin reactive surface layer with a well-defined thickness is created B) layer removal: the modified layer is more easily removed than the unmodified material. [2-4]

Here we study a Fluorocarbon(FC)-based ALE process for controlling the etching of silicon dioxide at the atomic level. Figure 1 shows the schematic of atomic layer etching process using Ar plasma and CHF_3 gas. During the saturative surface reaction (Figure 1(b)), CHF_3 is injected in the steady state Ar plasma. CHF_3 breaks and forms some fluorocarbon polymer on the SiO_2 surface. CHF_3 is then purged from the chamber and FC polymer is a source of fluorine, which reacts with SiO_2 modifying its surface (Figure 1(c)). For low energy Ar^+ ion bombardment conditions, the physical sputter rate of the substrate vanishes, whereas the modified surface can be etched when FC reactants are present at the surface (Figure1(d), (e)).

With the goal of achieving high selectivity FC-based ALE, we first investigated the etching per cycle (EPC) using spectroscopic ellipsometer on unpatterned surfaces. Using CHF_3-based ALE for SiO_2 etching, we proved ALE self-limiting behavior with etching rate of 6 Å/cycle. Figure 2 shows SiO_2 features varying the ion power during the removing step (which decrease moving left to right) etched using different masks: ZEP and Chromium. Using a Cr mask (Figure 2: Row 2) the EPC is similar to the one of flat surfaces. Instead, SiO_2 features using ZEP mask (Figure 2: Row 1) have an EPC 50% higher than expected. Polymer mask (ZEP) is a source of carbon, hydrogen and oxygen, which interfere with the etch process bringing it out of the self-limiting window. SiO_2 features etched using lower DC bias (17 V) are aspect-ratio independent and results in a low degree of physical/ionic etching.

A successful application of the FC-ALE approach has been demonstrated. Overall, the cyclic CHF_3/Ar etch has proven to pattern features well with an hard mask, with great potential for significant improvement in overall etch performance.

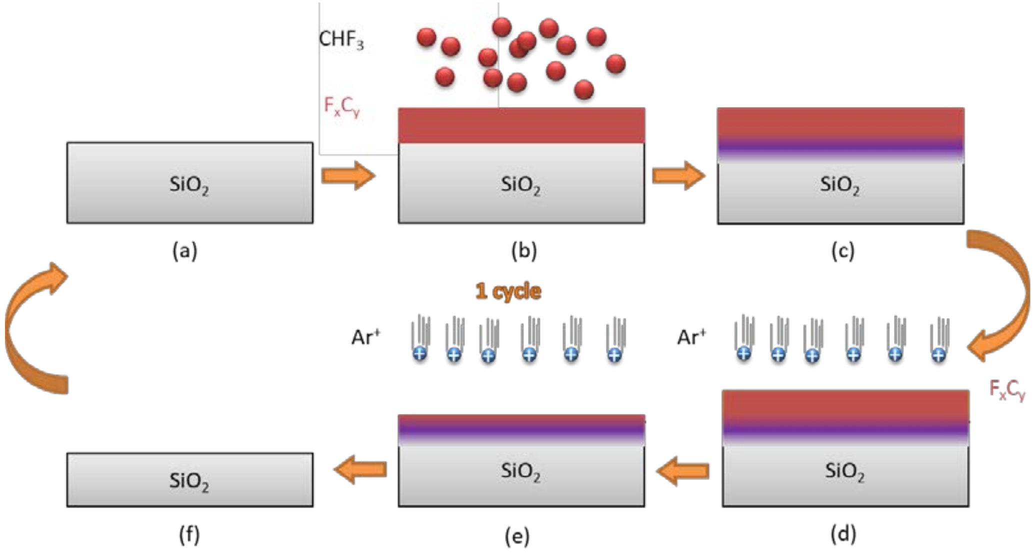

Figure 1. Schematic of one cycle of Fluorocarbon-based ALE process. (a) Starting surface: 250nm thermal silicon oxide. (b) Saturative surface reaction. (c) Gas purge and surface modification. (d) and (e) Release mechanism: Ar ions are accelerated toward the surface with enough energy only to remove the FC and the F-modified SiO_2 layer. (f) ALE product.

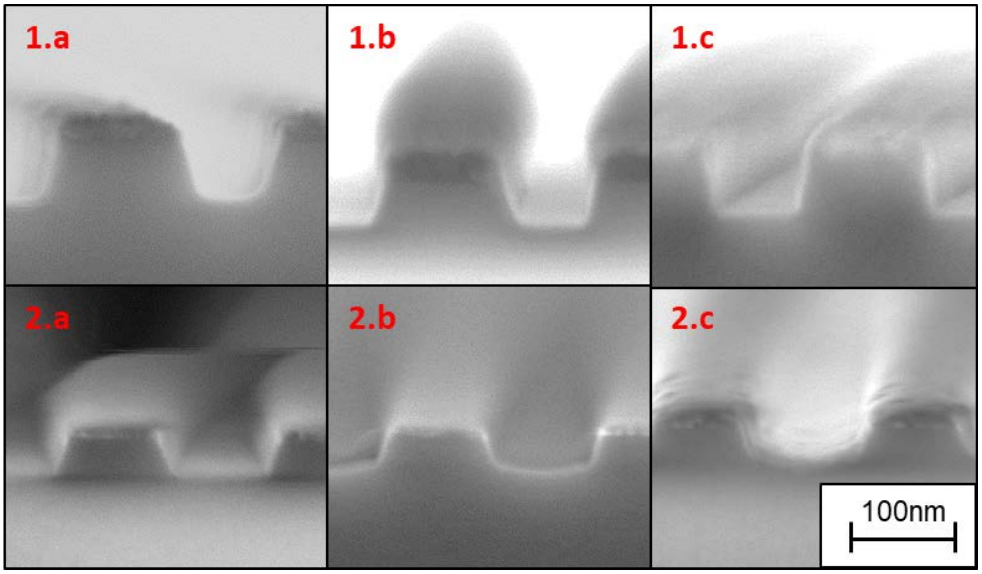

Figure 2. SiO_2 etching of 100 nm features with 60 cycles CHF_3-based ALE using different masks. Raw 1: 70 nm ZEP; Raw 2:10 nm lift-off Chromium (Cr).SiO_2 features have been etched using CHF_3-based ALE at different Ar^+ ions powers during the removal step (Figure 1(d) and (e)). Column 1: DC_{bias} = 25 V; Column 2: DC_{bias} = 22 V; Column 3: DC_{bias} = 17 V.

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