Selective Fluorocarbon-based Atomic Layer Etching in a conventional parallel-plate, capacitively coupled plasma

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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. [2,3]

Here we study a Fluorocarbon(FC)-based ALE process for controlling the etching of several substrates at the atomic level. Figure 1 shows a schematic of an atomic layer etching process using a steady state Ar plasma and a FC gas. A periodic fluorocarbon gas injection enables control of the deposited FC layer thickness in the one to several Angstrom range (Figure1: 1. Pulse) and chemical modification of the surface. 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: 3. Etch). [4]

With the goal of achieving high selectivity FC-based ALE, we study the etching of different materials under different FC chemistry. Etching rate per cycle is first investigated using spectroscopy ellipsometer on unpatterned surfaces. Using CHF_3-based ALE for SiO_2 etching, the etching rate is 8.5Å/cycle. Figure 2 shows SiO_2 features varying the critical dimensions (which decrease moving left to right) etched under different conditions. SiO_2 features etched using an ALE process (Figure 2: Row 1) are aspect-ratio independent compared to the features obtained with a continuous RIE process (Figure 2: Row 2). It is worth noticing how the results change when higher DC bias is used in the etch step of the ALE process (Figure 2: Row 3). This case is dominated by sputter etching with results in a high degree of physical/ionic etching.
A successful application of the cyclic ALE approach has been demonstrated. Overall, the cyclic FC/Ar etch has proven to pattern features well (Figure 2: Row 1), with great potential for significant improvement in overall etch performance.

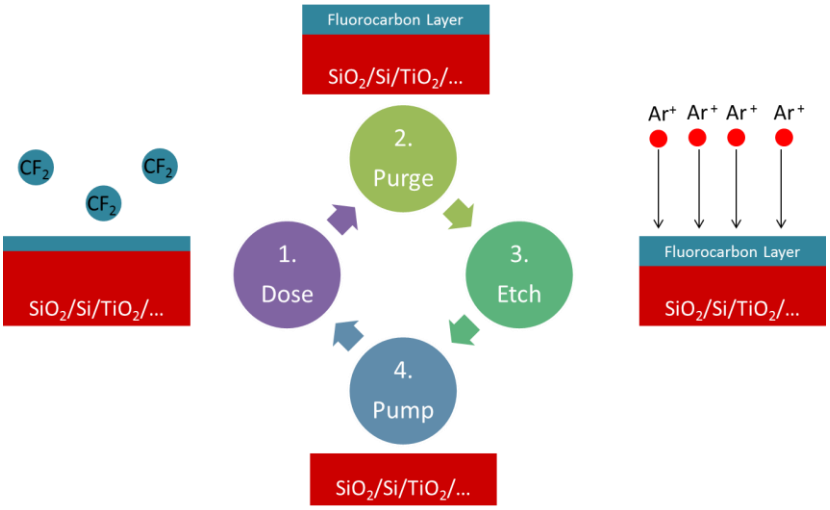

Figure 1. Schematic of one cycle of a typical ALE process. The surface modification step (1. Dose) includes self-limited adsorption and short deposition, followed by pump-out (2. Purge). Low energy Ar^+ ion bombardment is used for selective removal of reacted region (3. Etch). For the substrate after one ALE cycle (4. Pump), the steps (1) through (3) will be repeated. The overall etch depth is produced by *n* ALE cycles.

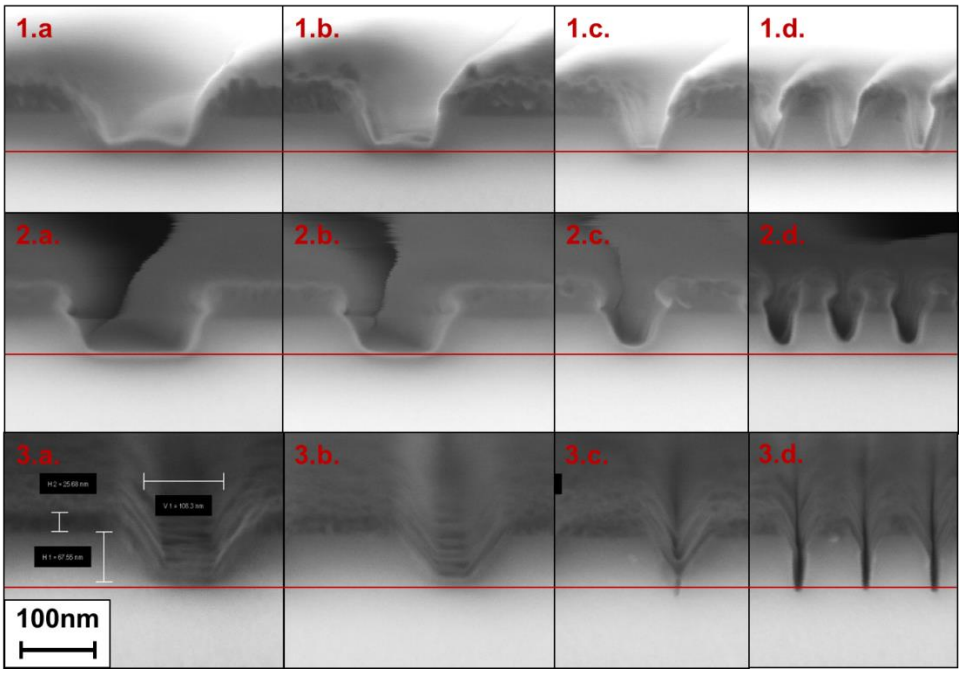

Figure 2. SEM images of evaluated silicon oxide features with varying the critical dimension Column a: 150nm; Column b: 100nm; Column c: 60nm; Column d: 40nm). Row 1: SiO_2 features have been etched using CHF_3-based ALE. Row 2: SiO_2 has been etched with standard continues CHF_3/Ar Reactive Ion Etching. Row 3:SiO_2 features etched using CHF_3-based ALE with higher DC bias.

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[3] Kanarik, Keren J., et al., Journal of Vacuum Science & Technology A, 33.2 (2015): 020802.
[4] Metzler, Dominik, et al., Journal of Vacuum Science & Technology A, 32.2 (2014): 020603.