Thermal Atomic Layer Etching of Silicon Using an Oxidation and "Conversion-Etch" Mechanism

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Thermal atomic layer etching (ALE) is based on sequential, self-limiting surface reactions. Thermal ALE is the reverse of atomic layer deposition (ALD). Thermal ALE has been demonstrated for many materials including Al_2O_3, HfO_2, ZrO_2, TiN and W. This talk will focus on thermal Si ALE using oxidation and "conversion-etch". During this process, the Si surface is oxidized to a silicon oxide layer using O_2 or ozone. The silicon oxide layer is then converted to an Al_2O_3 layer using trimethylaluminum (TMA) [1]. Subsequently, the Al_2O_3 layer is fluorinated by HF to an AlF_3 layer prior to the removal of the AlF_3 layer by a ligand-exchange reaction using TMA [1]. This reaction sequence is shown in Figure 1.

Si ALE was studied using silicon-on-insulator (SOI) wafers in a warm wall reactor with a hot sample stage. *In situ* spectroscopic ellipsometry (SE) was employed to monitor the thickness of both the silicon and the silicon oxide layer during Si ALE. These studies observed that the silicon film thickness decreased linearly with number of reaction cycles while the silicon oxide thickness remained constant. Using an O_2-HF-TMA reaction sequence, the Si ALE etch rate was 0.4 Å/cycle at 290°C as shown in Figure 2. Comparable etching rates were observed using ozone instead of O_2 as the oxidant.

Thermal Si ALE should be useful in advanced semiconductor fabrication. Thermal Si ALE could also be utilized for atomic-scale polishing and cleaning of silicon surfaces. In addition, there may be applications in other areas such as silicon-based optoelectronics, photonics and MEMS fabrication.

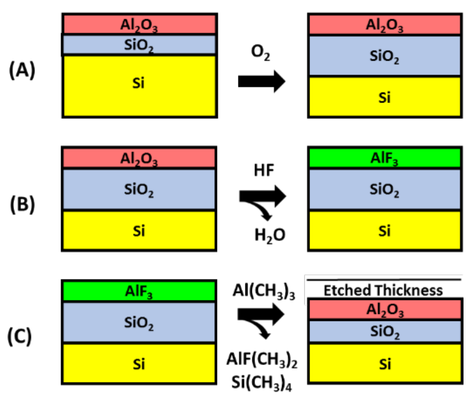

Figure 1. Thermal Si ALE based on (A) oxidation; (B) fluorination; and (C) ligand-exchange and conversion.

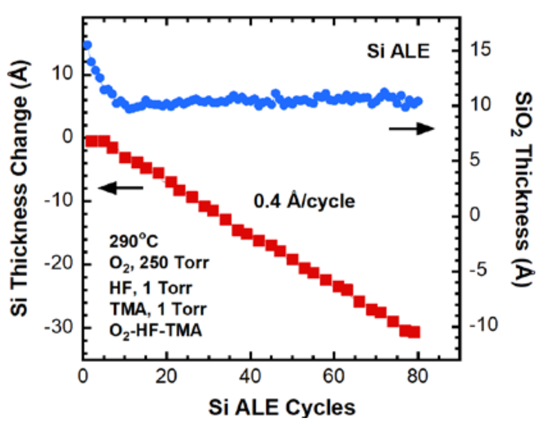

Figure 2. Si and SiO_2 film thicknesses during thermal Si ALE using sequential exposures of O_2, HF and TMA.

[1] J.W. DuMont et al., *ACS Appl. Mater. & Interfaces* **9**, 10296 (2017).
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