Thermal Atomic Layer Etching

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Thermal atomic layer etching (ALE) is based on sequential, self-limiting reactions that yield controlled etching at the atomic level. Thermal ALE utilizes gas phase precursors and accomplishes etching without the ion bombardment employed in plasma ALE. Because there are no line-of-sight restrictions, thermal ALE yields isotropic etching. Thermal ALE can be viewed as the reverse of ALD.

The mechanisms of thermal ALE are based on surface modification and then volatilization of the modified surface layer. Fluorination is an important surface modification. Ligand-exchange reactions are useful to remove the modified surface layer. Al_2O_3 ALE using HF and $Al(CH_3)_3$ as the reactants is a model for the fluorination and ligand-exchange mechanism.

Other pathways for thermal ALE are possible. The surface of the initial material can be converted to a different material that can be etched. SiO_2 ALE using $Al(CH_3)_3$ and HF is an example of "conversion etch". Oxidation to a metal oxide is a surface modification that can lead to removal by fluorination to a volatile fluoride. TiN ALE using O_3 and HF is representative of this thermal ALE mechanism.

Thermal ALE will have many applications in atomic scale processing. Isotropic etching will be useful for etching three-dimensional structures such as nanowires. Surface smoothing resulting from thermal ALE will be helpful for reducing line edge roughness. When there are nucleation delays in ALD, deposition-etch back methods will be able to prepare ultrathin and conformal films.