Tutorial Abstract

Fundamentals of ALE – Optimizing Passivation and Etch*

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The ideal process of plasma based atomic layer etching (ALE) consists, in principle, of two independent self-limiting steps. The first is passivation of an atomically smooth surface with plasma produced radicals with the goal of lowering the binding energy of the surface resident atoms. The second is removal of the passivated layer of atoms with the activation energy provided by plasma generated ions of carefully controlled energies. Ideal ALE, the removal of a single monolayer per cycle, is rarely achieved. There are narrow process windows in terms of how much activation energy can be delivered during the passivation step and how many passivants can be present during the etch step. In addition to the intrinsic chemistry of the ALE process, the quality of the process is ultimately determined by how well the fluxes delivered by the plasma to the surface can be controlled – all of which contribute to the ideality of the process.

ALE of dielectrics (ALE-D), typically using fluorocarbon gas mixtures, proceeds through deposition of a thin polymer layer which provides the precursors for the etch step. As such, ALE-D begins as being non-ideal as the passivation step is not self-limiting. ALE-D is perhaps better described as controlled EPC (etch-per-cycle). Depending on polymer thickness and ion energies, the EPC can be a fraction of monolayer or many monolayers.

In this tutorial, ideal and non-ideal ALE processes will be reviewed with an emphasis on the plasma properties required to achieve ideal behavior. Examples will be used from computer modeling of reactor scale plasma generation of passivants and etchants, and feature scale profile simulation. Halogen plasma based ALE of conductors will be used to illustrate the process window requirements for ideal EPC. Simulation of ALE-D of SiO_2 and Si_3N_4 will be used to illustrate how control of plasma properties can produce controlled EPC, selectivity and surface smoothness.

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