Etching and Deposition Modeling Using Level Set Methods

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Several silicon dioxide chemical vapor deposition processes using high density plasma sources have been recently proposed in the literature [4,6] for deposition of self-planarizing inter-level dielectric deposition. All these processes exhibit the competitive effect of simultaneous deposition and etching mechanisms. In previous papers [1,2,3], a level set approach was developed for etching and deposition simulations for 2D and 3D profiles, including the effects of complex sputter laws under ion milling, visibility, material-dependent etch rates, and sensitive flux integrations. Here, we present the extension of that work to arbitrary 3D geometries under simultaneous etching and deposition, including re-deposition, re-emission with variable sticking coefficients and multiple effects.

Level Set Methods

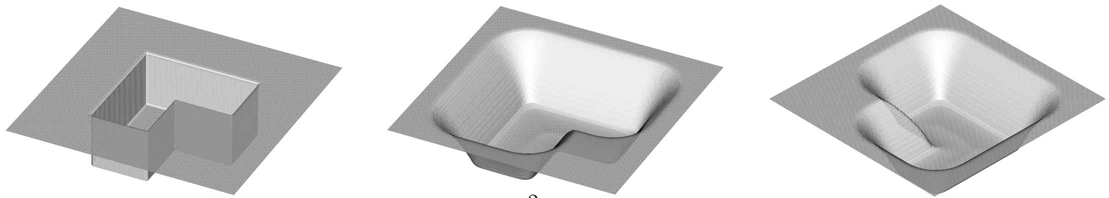
Level set techniques [7], numerically approximate the equations of motion for a propagating front by transforming them into an the unique solution of an initial value partial differential equation. Complex motion, particularly those that require surface diffusion, corners and cusps, sensitive dependence on normal directions to the interface, and sophisticated topological breaking and merging, result from a straightforward implementation of the scheme, with no user intervention.

More precisely, level set methods take the perspective of viewing the moving interface as the zero level set of a function $\phi(x, t = 0)$. An evolution equation [7] for the interface moving with speed F in its normal direction is given by $\phi_t + F|\nabla\phi| = 0$, where $\phi(x, t = 0)$ is given. The surface $\phi = 0$ corresponding to the propagating hypersurface may change topology, as well as form sharp corners, Finite differences lead to a numerical scheme to approximate the solution, and intrinsic geometric properties (normal vectors and curvature) are easily determined from the level set function. The formulation is unchanged for propagating interfaces in three dimensions. The technique is robust, completely stable under arbitrary geometries, and has a strict error term which is controlled by the time step, space step, and order of the scheme. For details, see [7,8,9,10,11].

Level Set Methods for Etching and Deposition

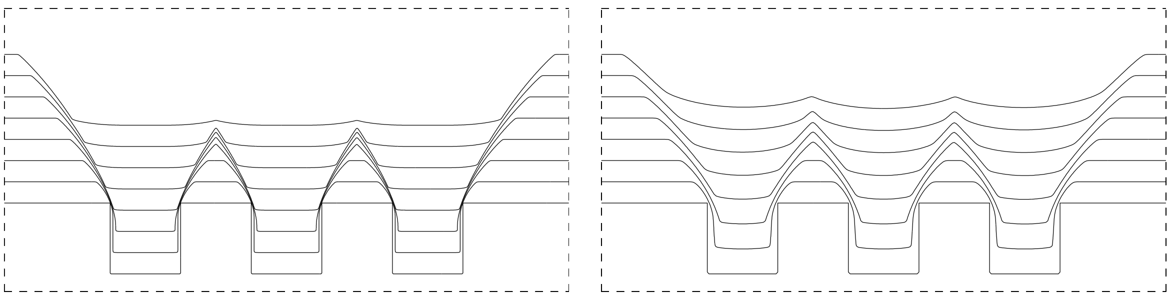
Recently reported evidence [5] strongly suggests that the deposition process can be modeled by a deposition rate mainly composed by ion induced deposition, low pressure chemical deposition, re-deposition from material back-scattered from the gas phase, and direct re-deposition from material sputtered from the surface. Furthermore, it is shown that the etch component as predominantly due to physical sputtering. This last component introduces instabilities in the simulation result when using surface advancement techniques such as string algorithms producing artificial roughness.

Figure 1, shows a level set simulation of etching of a saddle surface under ion milling with a non-convex speed law. Figure 3 includes physical sputtering from a vertical ion-milling component and two deposition components: (a) direct deposition with visibility and (b) a conformal deposition associated with small sticking coefficient. On the left, the ion-induced deposition is 60% while the uniform deposition is 40%; on the right, all of the deposition is due to the conformal term. The etching component increases from top to bottom; we note that the increase in etching produces faceting, however the step coverage on the right column is preserved independent of the ion-milling effects. Figure 2 shows a combination of ion-milling and ion-induced sputtered re-deposition, together with conformal deposition and direct deposition. On the left the ion-induced sputter re-deposition is set to zero, on the right the etched material is re-emmitted.



$Initial\ \ Shape : T = 0$ $\quad F = [1 + 4\sin^2(\theta)]\cos(\theta) \quad T = 8$ $\quad Final\ Rotated$

Figure 1: Ion-Milling of Saddle Surface



No re-deposition With re-deposition

Figure 2: Combination of ion-milling, direct deposition and conformal deposition

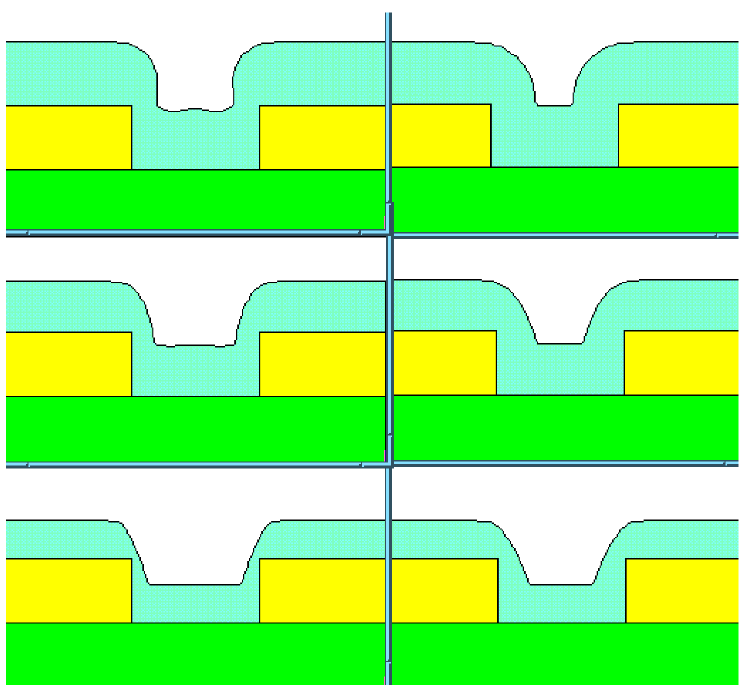


Figure 3: Ion-Milling plus Deposition

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