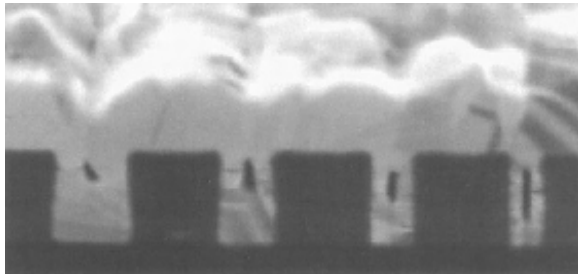


Superconformal ElectroDeposition in Semiconductor Processing

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Summary: We have developed numerical algorithms for solving partial differential equations on irregular domains with moving interfaces, and use these techniques to model the electrodeposition process in semiconductor manufacturing in both two and three dimensions. Our results allow us to track the position of the interface between the metal and the electrolyte as the features are filled and to determine which initial configurations and physical parameters lead to superfilling.

Electrodeposited copper can be used as the material for on-chip trenches and vias. The process of copper electrodeposition depends on the use of additives that affect the local deposition rate and this leads to superconformal filling of trenches.



An image of copper deposited from electrolyte. Voids are apparent in the trenches.

Early modeling studies focused on leveling theory in which the growth rate is dependent on the accumulation of inhibiting species onto the metal surface. Such leveling methods are not very successful in explaining the superfilling phenomena. Subsequently, curvature-enhanced

accelerator coverage (CEAC) has been proposed as the mechanism behind this process. According to the CEAC mechanism, deposition on a non-planar surface is accompanied by changes in the local surface area which affect the local adsorbate surface coverage. The coverage increases on concave segments and decreases on convex segments. This leads to bottom-up filling of features since the deposition rate is proportional to the catalyst coverage.

We have developed a complete and general numerical approach for modeling this deposition process: more importantly, our approach applies to a host of physical phenomena in which one must solve partial differential equations on moving irregular interfaces. Our approach, based on a combination of level set methods, Fast Marching techniques, material transport methods, immersed interface schemes and multigrid methods, is considerably faster than existing ones. Most of the calculations are performed only in the desired domain

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instead of in an extended rectangular domain, and are aided by the use of a one-sided version of the multigrid method to solve the corresponding large sparse linear systems.

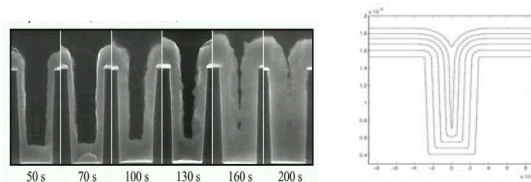
In more detail, first we were able to develop a new model of superconformal electrodeposition. This model naturally arises from a conservation law form of surface additive evolution. It allows us to perform a careful analysis of how superfilling depends on the choice of physical parameters, with close comparison to experiment.

To solve this model, we developed several new numerical techniques. First, we invented a conservative material transport level set method in two and three dimensions for interfaces that carry scalar fields as they evolve. This technique exploits upwind solvers from hyperbolic conservation laws to accurately track the evolving embedded scalar function for the accelerator coverage.

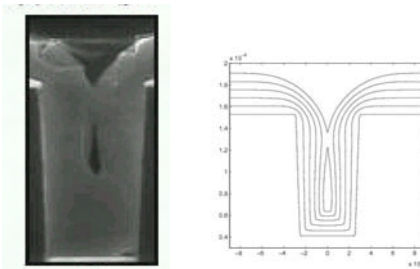
Next, we developed an immersed interface type method for building one-sided difference operators for complex interfaces with thin arms and fingers. This is required to deal with the narrowing trench and void formation phenomenon associated with delicate deposition problems.

Finally, we devised a multigrid method in two and three dimensions for solving one-sided diffusion equations with irregular moving interface. Unlike previous techniques, this allows us to greatly accelerate the calculations by focusing

resources on the relevant side of the interface.



Electrodeposition without Voids: Experiment (left), Simulation (right)



Electrodeposition with Voids: Experiment (left), Simulation (right)

References:

J.A. Sethian, *Level Set Methods and Fast Marching Methods*, Cambridge University Press, 1999.

J.A. Sethian, and Y. Shan, *Solving Partial Differential Equations on Irregular Domains with Moving Interfaces, with Applications to Superconformal Electrodeposition in Semiconductor Manufacturing*, submitted, *J. Comp. Physics*, 2007.

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