Two-dimensional Computational Model for Electrochemical Micromachining with Ultrashort Voltages Pulses

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The manufacture of micromechanical devices with sub-micrometer precision is one of the key issues facing a variety of nascent technologies, ranging from biological and electrochemical sensors to chemical microreactors. These applications place new demands on traditional fabrication techniques involving lithography, deposition, ion implantation, which often exceeds current limitations or introducing cost and performance issues. Therefore, the development of novel techniques is necessary to overcome these processing concerns.

Recent results using electrochemical systems show promise for the areas of three-dimensional etching, high aspect ratio etching, and controlled deposition. These methods employ a “tool” electrode held in close proximity (~1 micron) to a reactive “substrate” electrode in the presence of an electrolyte and utilize ultrashort (~50 ns) voltage pulses to modify the substrate surface selectively. The shape and feature resolution of synthesized structures would be determined by a complex combination of i) charging and discharging of electrochemical double layers at electrode surfaces, ii) electrochemical reactions on the electrodes, and iii) transport of molecules to the electrode surface. Experiments may provide many clues to the fundamental behaviors of electrochemical systems, but their interpretations often remain controversial due largely to difficulties in direct measurement. While current experimental techniques are still limited to providing complementary real space information, the interplay between experiment and theory will contribute to uncovering the intricate kinetic phenomena.

In this talk, we present our multiphysics computational model for electrochemical micromachining with ultrashort voltage pulses. This theoretical approach integrates i) a circuit model to describe charging and discharging of electrochemical double layers and electric field variation in electrolytes and ii) the level set method to simulate feature profile evolution during electrochemical etching. Our simulation results of transient current responses and etch profile evolution are qualitatively in excellent agreement with experimental observations. From our simulations, we find that the resolution of etched features is a strong function of the substrate double layer capacity which may be controlled by electrolyte concentration and pulse duration.