Time Dependent Effects of Electron Beam Induced Etching (EBIE)

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The use of focused electron beam induced etching has potential benefits over focused ion beam (FIB) sputtering for nanoscale patterning, repair, and prototyping. The electron beam has higher spatial resolution potential and less collateral damage to the substrate. EBIE offers the potential for higher etch selectivity than FIB due to the fact that it is an entirely chemical process, rather than the sputtering that occurs under FIB.

In order to accomplish electron beam induced etching, a precursor gas is directed towards and adsorbs on the surface of a substrate which is simultaneously (or sequentially) irradiated with a focused electron beam. The electron can inelastically dissociate the otherwise stable precursor molecule into radical by-product species. These radicals react with the surface atoms of the solid and form volatile molecules which desorb from the surface after a specific residence time associated with the adsorption energy of the species. The result is a site-selective nanoscale etching process that is controlled by the rastered electron beam.

We have recently experimentally investigated and modeled the effects of a static electron beam and the various process parameters on the resultant etch rate and profile. It was found that under sufficiently high electron flux, the etch product does not have time to desorb from the surface before being dissociated by a subsequent electron.[1] This results in re-deposition of the substrate material and near-zero etch rate. The radial electron flux distribution of primary, secondary, and backscattered electrons can result in a "moat" shape etch profile.

In this work, we have extended our previous steady state simulations to include time-dependence, which allows us to simulate the effects of loop and dwell time. The EBIE process can be modeled by a set of simultaneous partial differential equations describing the various surface phenomena of adsorption, dissociation, desorption and diffusion. Investigating the time dependent behavior shows that there are four temporal regions of interest: the *precursor depletion/product accumulation region*, the *product depletion region*, and the *steady state region* during the beam dwell time as well as the *refresh region* during the beam loop time. The effects on the final etch shape from these regions will be discussed in detail. We will demonstrate the dramatic effect that the pulse conditions have on the etch shape and resolution as a result of the time dependent beam parameters. The etching model will be used to demonstrate how the process variables affect the various regimes and can be optimized for the best performance.

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[1] M.G. Lassiter, P.D. Rack, *Nanotechnology*, **19** 455306 (2008)

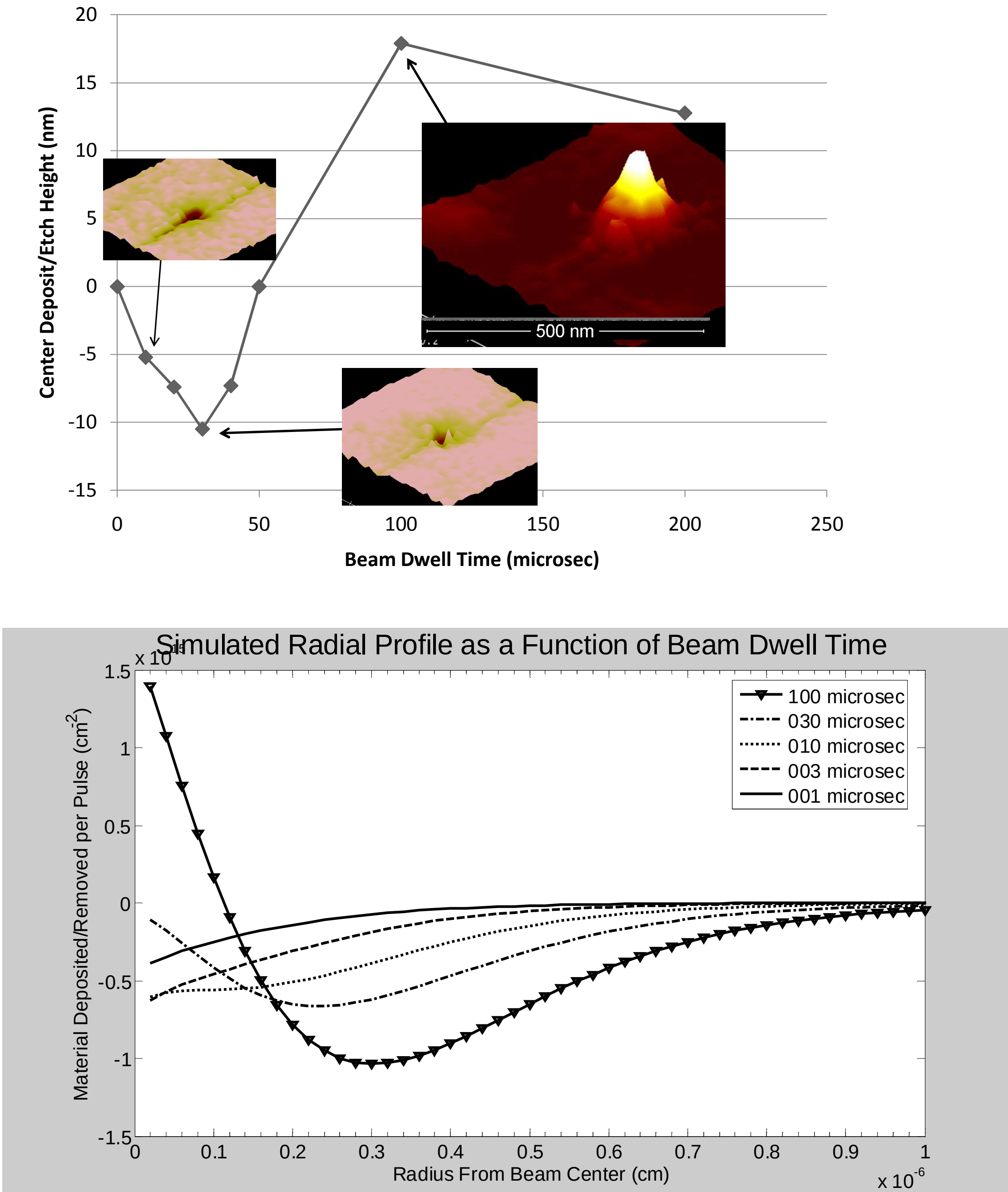

Figure 1: *Evolution of the Etch Shape Due to Beam Dwell Time*: (Top) Plot of deposit/etch height versus beam dwell time for 10^5 Pulses and a constant refresh time. For short beam dwell times net etching is observed. For long dwell times, a net deposit occurs under the beam center. The scale marker is for x- and y-directions only. (Bottom) The EBIE precursor-product model predicts the observed behavior. For short dwell times, the center etches, while for longer dwell times deposition is observed under the beam center and a "moat" shape evolves.