Nanoscale Focused Electron Beam Induced Etching: Monte Carlo Simulations

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Focused beam (electron-ion-photon) induced processing has long been utilized as a micro-/nano-scale direct synthesis method for both additive (via deposition) and subtractive (via etching) machining for a variety of editing and prototyping applications. Nanoscale lithography mask editing is one critical area which is pushing the limits for these beam induced processing methods. Beam damage associated with liquid gallium and the recently developed gas field ion source limits their utility in lithography mask repair due to the stringent optical requirements. Thus, electron beam induced processing for mask repair of both clear and opaque defects is the method of choice.

To understand the fundamental electron-solid-precursor interactions, a Monte Carlo electron-solid simulation has been developed with an appropriate precursor gas routine which emulates adsorption/desorption, surface diffusion and electron stimulated reactions. The simulation was recently modified to handle electron beam induced etching. The electron beam induced etching of silicon dioxide is studied at low and high energies, short and long dwell times and various etch precursor gas conditions to elucidate important rate limiting regimes. Furthermore, the temporal behavior of the high-aspect ratio etch process is demonstrated. Simulation results are compared to various experimental conditions to validate appropriate parameters.

Figures 1 depicts the top 20 nm etching structures at 1ow (left) and high (right) beam energies at different values of current and dwell time after running 200k electrons. The color code illustrates the type of specie responsible for the molecule's etch during the process, namely: primary, forward-scattered, backscattered, and secondary (I and II) electrons. Figure 2 illustrates the incremental etching yields for the various electron species contributing to the etch process.

In this presentation we will overview the Monte Carlo simulation. We will then illustrate how various parameters affect the resolution and etch rate of the electron beam stimulated etch process. We will demonstrate how beam parameters (beam energy, current, and dwell and refresh time) precursor parameters (flux, residence time, surface diffusion coefficient, dissociation cross-section) and material (secondary electron yield, density) all contribute to the

nanoscale etching process.

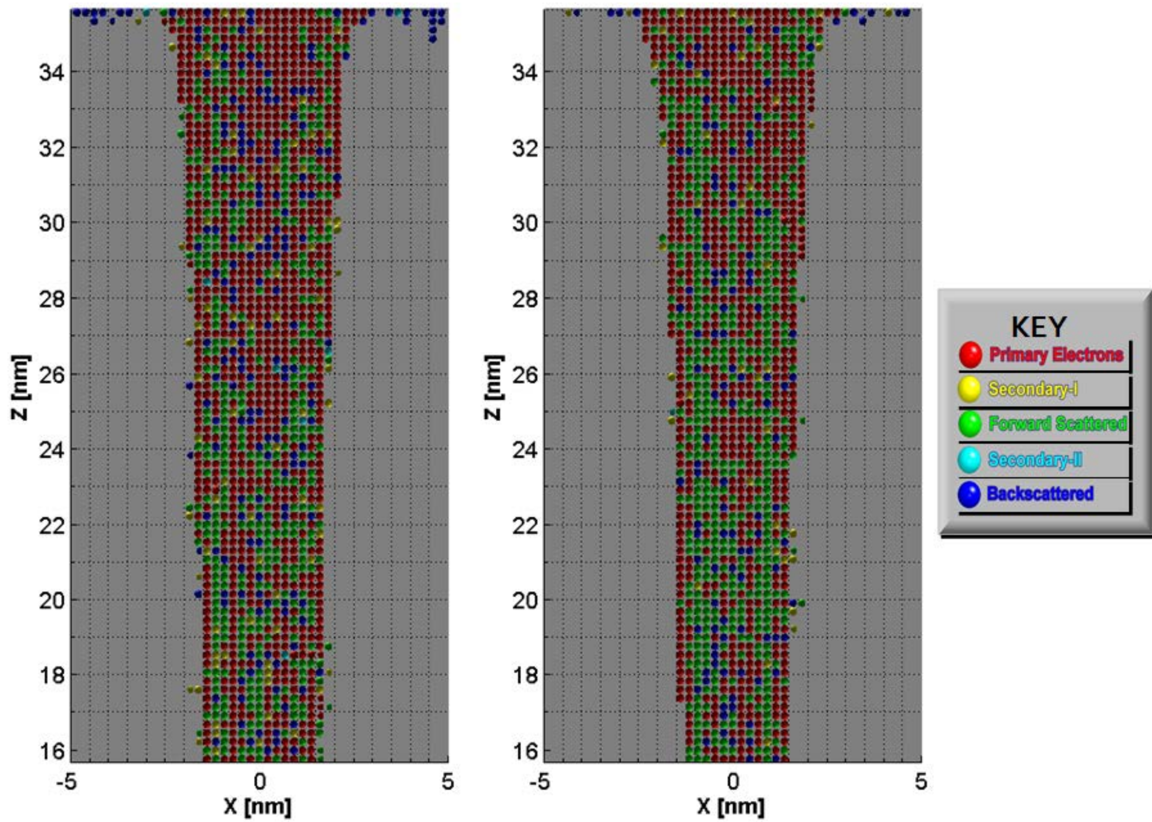

Figure 1: Etched nanostructures: The middle slices (top 20 nm) of the etched nanostructures at low (left) and high (right) beam energies.

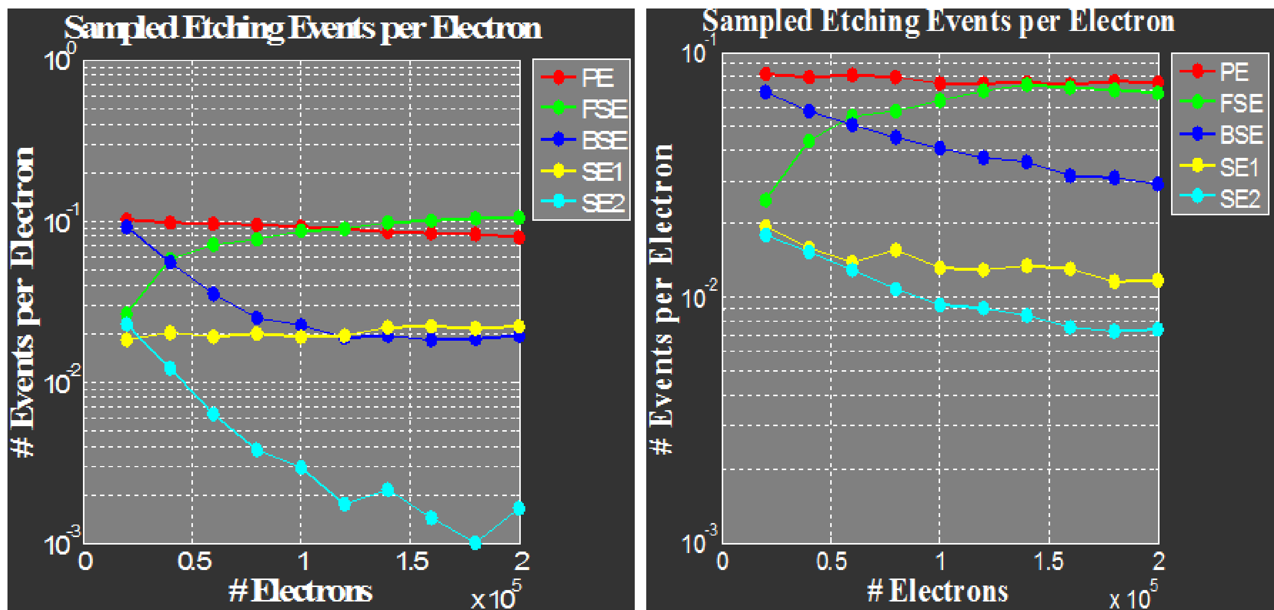

Figure 2: Incremental etch yield of various electron species for low (left) and high (right) beam energies