Nanoscale Electron Beam Induced Etching (EBIE)

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Electron beam induced etching (EBIE) is a direct write technique for nanoscale patterning, prototyping and device repair. EBIE is an alternative to focused ion beam (FIB) etching and offers better spatial resolution potential than FIB due to the smaller beam spot size. The electron beam imposes far less collateral damage to the substrate than the Ga^{+} ion beam as the FIB etching processes are mostly due to physical sputtering of the substrate atoms with some chemical etching assistance possible. This often leads to poor selectivity against other materials. EBIE processes are entirely chemical and can offer high etch selectivity between different materials.

In order to accomplish EBIE etching, a precursor gas must impinge upon the surface of the substrate and locally adsorb. When an energetic electron inelastically interacts with the adsorbed precursor molecule, there is a probability that some of the electron's energy will be transferred to the precursor molecule and result in the dissociation of the stable precursor molecule into its constituent atoms. These atoms can subsequently react with the surface atoms of the solid and form volatile molecules. The volatile reaction products must desorb from the surface for net material removal to take place thus exposing sub-surface solid atoms to fresh precursor species. The desorbed etch products are pumped out of the chamber by the evacuation system. The result is a site-selective nanoscale etching process that is controlled by the rastered electron beam.

The EBIE process is modeled using a system of partial differential equations to describe the precursor and etch product gas concentrations on the surface of the substrate, accounting for gas phase adsorption of impinging precursor molecules, adsorption lifetime, and e-beam induced dissociation of the precursor and the etch product. The electron flux is modeled using a Monte Carlo technique to generate realistic spatial distributions of the electron flux at the surface specific to the substrate material. Combining the EBIE and electron flux models results in a model that can describe the spatial distribution of the etch rate as a function of the various processing parameters. We have previously described the results of a static e-beam induced etching model[1], and other variations on the topic have been published[2,3]. In this work, we present the effects of a scanning or pulsed beam. The beam dwell time as well as the beam refresh time have a significant impact on the precursor and product distribution and ultimately the etching performance (Figure 1). The Precursor-Product EBIE model can improve the understanding of the EBIE process and help optimize the beam parameters for improved resolution and etching rate (see Figure 2).

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[1] M. G. Lassiter et al., "Understanding Electron Beam Induced Etching (EBIE) Processes", Presented at **AVS54**, Seattle, WA (2007), manuscript in preparation.
[2] I Utke et al., J. Vac. Sci. Technol. B, **25**, 6, 2007
[3] C J Lobo et al., Nanotechnology **19**, 2008

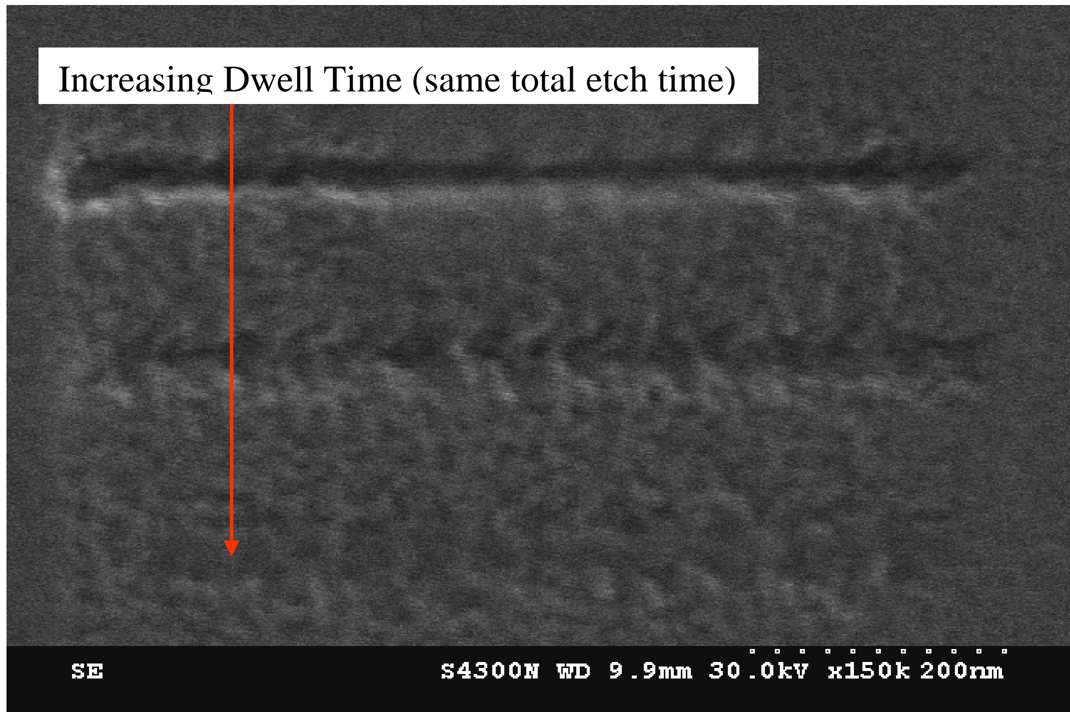

Figure 1: *Effect of Dwell Time on EBIE*: The scanning rate was varied for the three line etches above during EBIE of SiO_2 using XeF_2. The case of the longest dwell time (bottom line) has the slowest etching rate. This is due to the dissociation of the etch product before it desorbs from the surface. With the short dwell time (top line), the beam moves away shortly after the etch product is formed, and during the subsequent refresh time allows the product to thermally desorb.

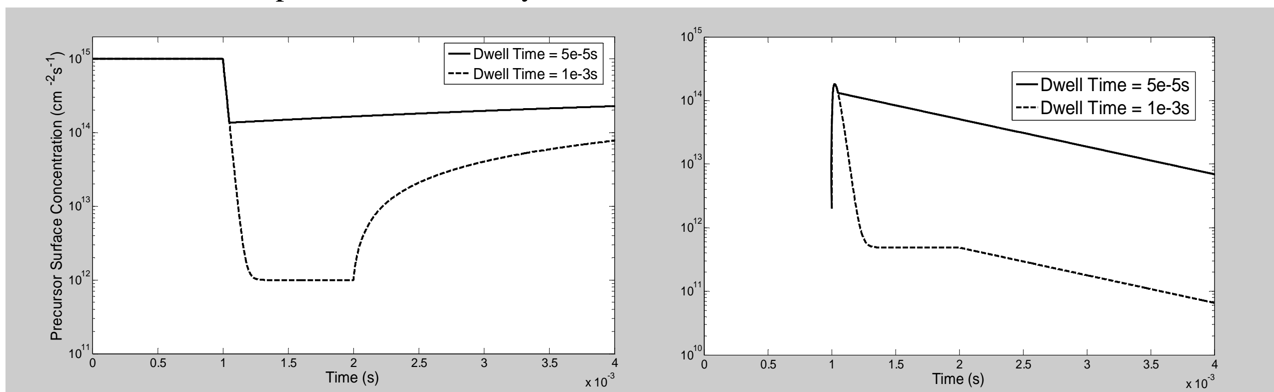

Figure 2: *Simulation of Effect of Dwell Time on EBIE*: A comparison of precursor (left) and etch product (right) for different e-beam dwell times during EBIE. In the case of the short dwell time, the etch product is formed and the beam moves on allowing for the product to desorb. For the longer dwell time, the product is formed; but is re-dissociated by the e-beam during continued exposure to the e-beam, converted back to the original substrate material, and results in retarding the overall etch rate. In this case, the shorter dwell time removes 10.4 times as much material relative to the longer dwell time in the same amount of time. In both cases the e-beam starts at $t=1.00x10^{-3}$s. In the case of the short dwell time, the beam turns off at $t=1.05x10^{-3}$s, and for the long dwell time the beam turns off at $t=2.00x10^{-3}$s.