Effects of energy and gas dynamics on the growth morphology and kinetics of electron beam induced deposition via a Monte – Carlo based, 3D simulation

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The rapid and precise direct write growth of nanoscale features by electron beam induced deposition (EBID) requires the optimization of the growth velocity while maintaining nanoscale feature dimensions. The complex EBID parameter space includes the precursor gas pressure, the primary electron beam energy and current, surface diffusion of the adsorbed gas, thermal effects on desorption, and the cascade of electron species produced by inelastic scattering processes. These variables affect the probability of precursor dissociation and hence determine the morphology and kinetics of the structure through a series of complex, coupled nonlinear interactions. A dynamic Monte-Carlo simulation was created to aide in the interpretation of experimental observations through its quantifiable output.

The 3D simulation includes all the aforementioned variables making it possible to elucidate the variables most significant in producing an experimentally observed growth phenomenon. The simulation imitates EBID growth for nanoscale, stationary and scanned electron beams with energies and currents characteristic of a conventional SEM. In this presentation, we will briefly overview the simulation and algorithms used to handle the electron-solid, electron-gas, and gas-solid interactions. Simulations of tungsten nano-structures from WF_6 in two specific studies are compared: the effects of beam energy and surface diffusion on the EBID process. Fig. 1 shows the pillar morphology, emissions, and deposition events for the two energies studied (1keV and 5keV). The 1keV pillar showed greater deposition efficiency due its emissions spectra overlapping the dissociation cross-section at higher probabilities. Fig 2. shows a summary of the gas dynamics which were examined (adding a monolayer, then surface diffusion, and finally a constant gas source at the simulation boundary). 2D cross-sections show how surface diffusion not only affects the lateral and vertical growth rates, but also the resolution because it can modify the growth regime from mass-transport limited to reaction-rate limited.

Finally, we will demonstrate the extension of our simulation to a rastered beam which can simulate the effects of parameters such as pixel dwell time, refresh rate, current, pixel overlap, gas pressure, etc.

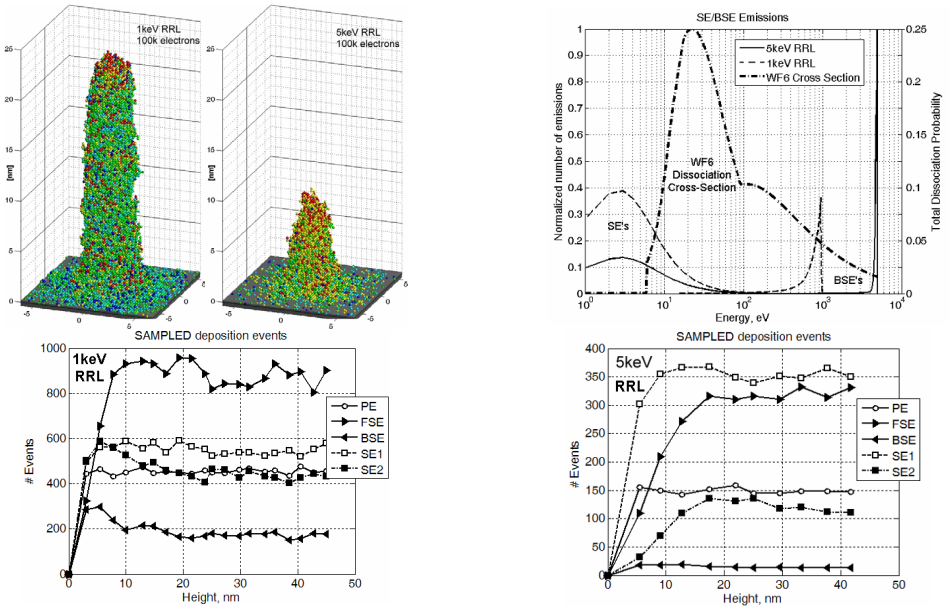

Fig 1: Energy Comparison: Top Left: Comparison the 1keV (left) and 5keV (right) pillars simulated under reaction-rate limited conditions (0.009pA, 7 Torr) and grown to 100,000 electrons. Top Right: SE and BSE emission spectra at the same number of electrons (2 million) with the total dissociation probability curve superimposed. Bottom: Deposition events based on electron type as a function of pillar height in the 1keV pillar (left) and the 5keV pillar (right), normalized to the number of sampled electrons (10k and 50k, respectively).

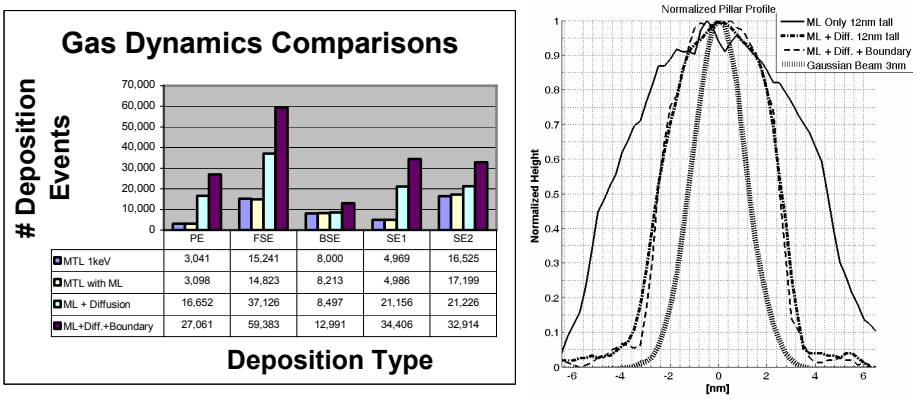

Fig. 2: Diffusion Comparison: Left: Comparison of deposition events for each of four runs: No monolayer (ML), ML only, ML + Diffusion, and ML+Diff.+Boundary source. Right: Morphology comparison of the last three gas dynamics simulations, taken at the same height and normalized with Gaussian beam profile.