Resolution and growth regimes in focused ion and electron beam induced processing

Ivo Utke, Vinzenz Friedli, Johann Michler

Empa, Swiss Federal Laboratories for Materials Testing and Research, Laboratory for Mechanics of Materials and Nanostructures, Feuerwerkerstr. 39, CH-3602 Thun, Switzerland

Local chemical reactions triggered by focused particle beams involve the physico-chemical processes: molecule adsorption, desorption, diffusion, and dissociation/fixation inside the irradiated area as depicted in figure 1. The mathematical description via the adsorption rate equation was set up by Zhdanov [1] in 1967 and by Müller in 1971 [2]. We solved this equation numerically for a Gaussian electron / ion distribution which allows fitting deposit shapes and quantifying minimum deposit dimensions, see figs. 2 and 3.

An important parameter which is governing the minimum dimension and shape is the ratio of the diffusion path of a molecule with respect to the FWHM of the beam (or its generated secondary electron distribution). Only in the electron/ion-beam-limited regime the deposit can maintain the resolution and approach the theoretically estimated minimum dimensions of 0.2 – 2 nm [3]. Parameters like molecule residence time, surface diffusion coefficient, surface coverage, electron/ion-impact dissociation cross sections, and sticking probability can be quantified from the deposit shape, see figure 4. The deduced dissociation cross section represents an “integral” value over the energy spectrum generated by the impinging beam.

With respect to Monte Carlo simulations, where the deposit shape was determined from the secondary electron emission [3,4], the above continuum model approach can be regarded as complementary and must not rely on energy-dependence assumptions of the dissociation cross sections. Thus gas-assisted electron *and* ion beam induced processing can be conveniently treated and compared within the same continuum model.

[1] G.S. Zhdanov, W.N. Verzner, Dokl. Akad. Nauk SSSR 176 (5) (1967) 1040.
[2] K.-H. Müller, Optik 33 (1971).
[3] N. Silvis-Cividjian, C. W. Hagen, P. Kruit, J. Appl. Phys. 98 (2005) 084905
[4] J. D. Fowlkes, S. J. Randolph, and P. D. Rack, J. Vac. Sci. Technol. B **23** (2005) 2825.

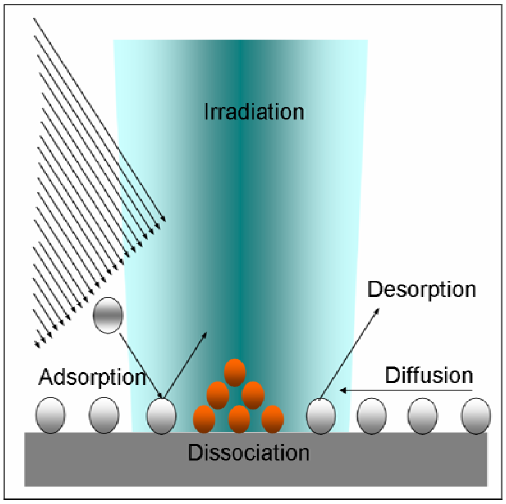

Fig. 1: Sketch of FEB and FIB induced deposition process. The physical sputtering during FIBID is not shown.

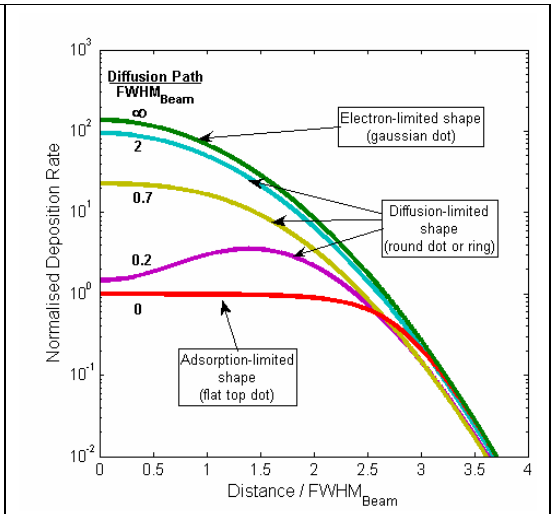

Fig. 2: Deposit shapes obtained from steady-state solutions of the adsorption rate equation.

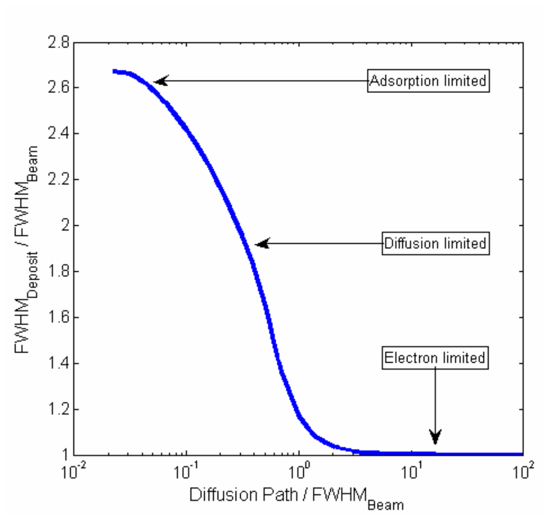

Fig. 3: Minimum deposit dimensions, $FWHM_{Deposit}$, from figure 2. Note that only in the electron (ion) beam limited regime the deposit can maintain the resolution given by the impinging electron (ion) beam.

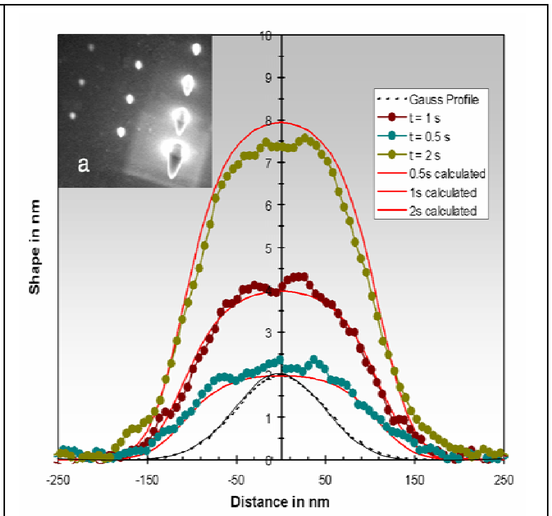

Fig. 4: Dot shapes from FEB deposits on membrane varying the exposure time, see inset with TEM tilt view. The impinging Gaussian beam is indicated: 25kV, 100pA, FWHM = 100 nm. The fit was obtained with a residence time τ = 21 ms, and a cross section σ = 0.9 Å^2.