Direct writing of high resolution, radially-symmetric nanostructures by simultaneous electron beam induced deposition and etching

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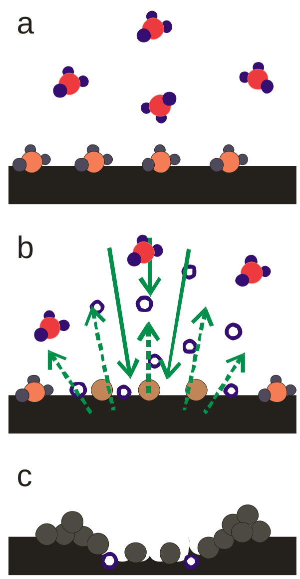
Electron beam induced etching (EBIE) and deposition (EBID) are direct-write nanofabrication techniques in which an electron beam is used to dissociate surface-adsorbed precursor molecules to achieve etching or deposition. In both processes, the precursor molecules are dissociated by electrons crossing a substrate surface, producing reactive fragments which convert surface material to volatile or nonvolatile reaction products, giving rise to etching or deposition under a focused electron beam (Fig. 1). Nanostructures that have been fabricated using EBID include gold and platinum-containing nanowires, nanotips for field emission and atomic and magnetic force microscopy, and metallic contacts to carbon nanotubes. The spatial resolution achieved by these techniques exceeds that of resist-based lithography, reaching 4 nm on thin substrates and at low electron doses on bulk substrates[1,2]. The attainable EBID resolution is generally limited by the electron flux distribution at the surface (which is broadened by emitted secondary and back-scattered electrons). Here we present simultaneous EBIE and EBID (EBIED) as a method for surpassing this resolution limit by using adsorbate depletion to induce etching and deposition in adjacent regions *within* the electron flux profile. Our results indicate the possibility of growth control of radially symmetric nanostructures at the sub-1 nm length scale on bulk substrates[3] (Fig. 2). The technique is well suited to the fabrication of ring-shaped nanostructures such as those employed in plasmonics, sensing devices, magnetooptics and magnetoelectronics.

1. O. Guise, J. Ahner, J. Yates, and J. Levy, Appl. Phys. Lett. **85**, 2352 (2004).
2. U. Hubner; R. Plontke; M. Blume; A. Reinhardt; and H. W. P. Koops, Microel.Eng. **57-8,** 953 (2001).
3. C. J. Lobo, M. Toth, R. Wagner, B. L. Thiel, and M. Lysaght, Nanotechnology **19**, 025303 (2008).



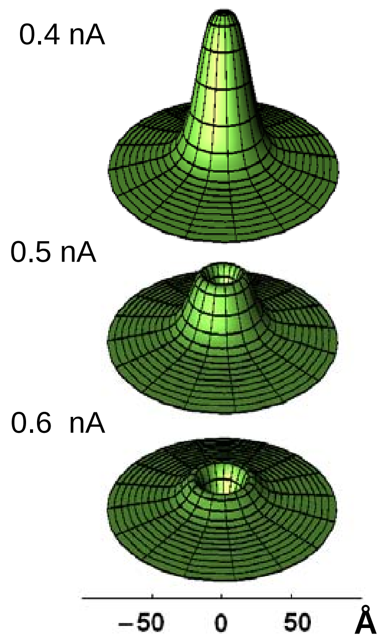


Fig 1. (a-c) Schematic illustration of electron beam induced etching and deposition: (a) precursor molecule adsorption and surface diffusion, (b) electron induced dissociation of adsorbed precursor molecules by the electron beam (full lines) and secondary and backscattered electrons (dashed lines), (c) deposition and surface material volatilization.

Fig 2. Simulated deposit morphologies produced by simultaneous deposition and etching using a 4 nm diameter primary electron beam and beam currents of 0.4, 0.5 and 0.6 nA. The deposition precursor partial pressure $P_d = 10^{-2}$ Pa and the etch precursor partial pressure $P_e = 10^2$ Pa. At the higher beam currents, depletion of deposition precursors under the beam causes the etching rate to exceed the deposition rate at the beam axis, resulting in ring-like deposits with sub-1nm inner diameters.