Combined Electron Beam Induced Deposition and Etching for 3D shape control

S. Hari, C.W. Hagen, P. Kruit
Department of Imaging Physics, Delft University of Technology, Lorentzweg 1, 2628 CJ Delft, The Netherlands
s.hari-1@tudelft.nl

J. J. L. Mulders, P. H. F. Trompenaars
FEI Electron Optics, Achtseweg Noord 5, 5651 GG Eindhoven, The Netherlands

3D shape control is an essential requirement in the development of novel lithography techniques such as Electron Beam Induced Deposition (EBID). While it is in principle a high resolution technique with 3 nm lines and spaces having been demonstrated [1], there is little control over the shape of the lines due to additional processes initiated by secondary and backscattered electrons from the substrate. The characterisation of the 2D size of sub-20 nm EBID lines carried out previously [2] reveals the extent of broadening due to these processes, typically resulting in a Gaussian line profile with sloping sidewalls (Figure 1). The goal of this work is to fabricate nanopatterns with vertical sidewalls, and therefore, well-defined widths. We present the application of Electron Beam Induced Etching (EBIE) to modify the 3D profile of EBID structures, as a technique which offers shape control while retaining all the advantages of electron beam induced processing. Carbon structures, approximately 500 nm thick, were patterned in an FEI Helios 650 Dual Beam system by EBID on a silicon substrate having a 20 nm gold-palladium layer. Using $MgSO_4.7H_2O$ as a supply for water molecules, 50 nm x 50 nm squares were etched by a 5 keV electron beam in the plane deposit, as depicted in Figure 2(a). Successful etching of carbon and an increase in depth with electron dose (from 3.2×10^6 C/m^2 to 48×10^6 C/m^2) can be seen from the FIB cross sections in Figure 2(b).

Consequently, the first experiment to etch the sloping sidewalls of an EBID structure was carried out. EBIE was performed next to the left and right edges of a 500 nm wide EBID structure by exposing large areas to a 5 keV electron beam in the presence of water molecules, as shown schematically in Figure 3(a). The FIB cross section of the structure before and after etching, shown in Figure 3(b) and (c), clearly shows the creation of vertical sidewalls upon etching. In addition, this technique provides flexibility in aspect ratio of patterned structures by allowing the modification of width with no change in height.

Based on this proof-of-principle, further experiments were performed and quantitative measures of size and shape control of EBID structures will be presented.

[1] J. C. van Oven et al., *J. Vac. Sci. Technol. B* **29** (6), 06F305-1 (2011)
[2] S. Hari et al., *J. Micro/Nanolith. MEMS MOEMS* **13** (3), 033002-1 (2014)

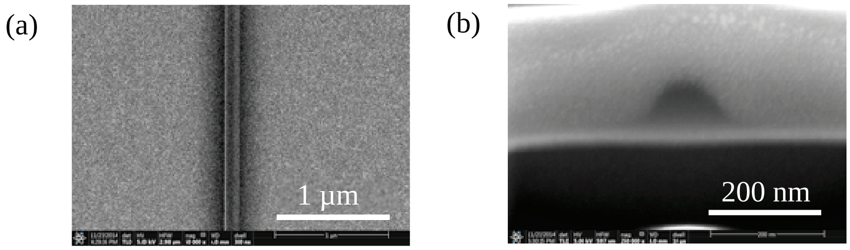

Figure 1(a) Top view and (b) FIB cross section of a typical EBID line, approximately 100 nm in height and width, patterned by line exposure with a 5 keV defocused electron beam.

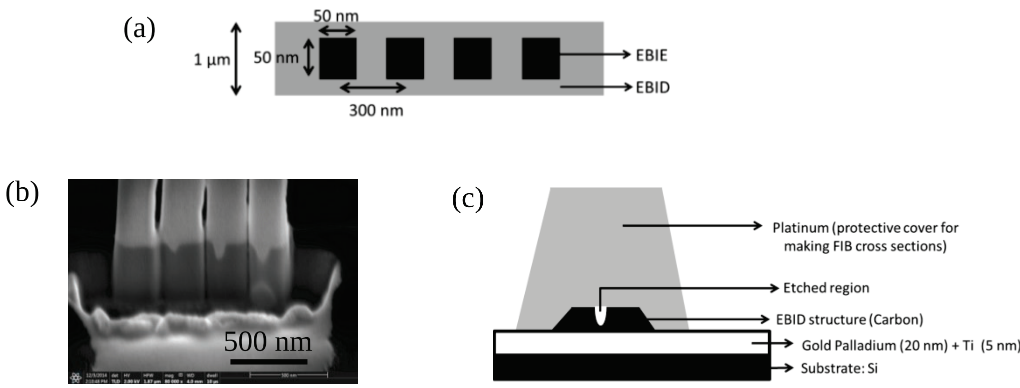

Figure 2(a) Schematic of 50 nm x 50 nm squares etched in a large plane carbon EBID deposit *(b)* Increase in etch depth with electron dose (L - R: 3.2 x 10^6 C/m^2 to 48 x 10^6 C/m^2) *(c)* Schematic of FIB cross sectioning after etching.

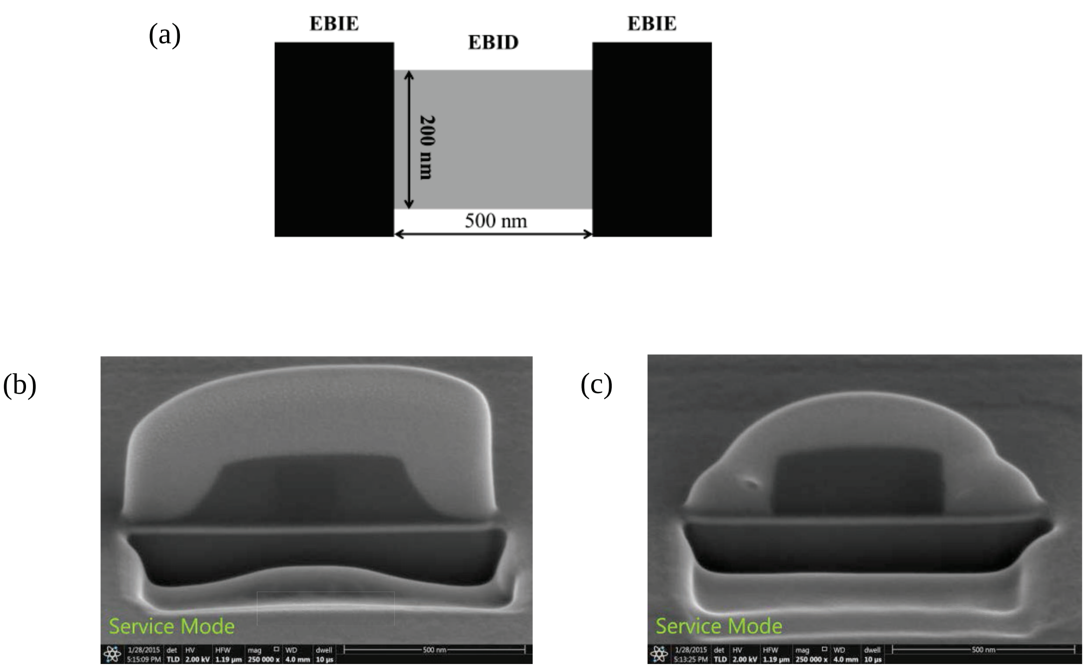

Figure 3(a) Schematic of large- area EBIE performed next to the left and right edges of the EBID structure *(b)* FIB cross section of as-deposited EBID structure and *(c)* EBID structure after etching, clearly demonstrating the creation of vertical sidewalls.