'Cleanroom in SEM'

C.W. Hagen, G. Jeevanandam, M. Scotuzzi, V. van der Meijden, N. Noordzij, R. van Tol, Y. van Goozen, P. Kruit
Delft University of Technology, Dept. Imaging Physics, Charged Particle Optics group, Delft, The Netherlands
c.w.hagen@tudelft.nl

Experiments involving micro-scale or nanoscale devices often require only one, or at most a few, functional devices. To fabricate such devices typically a cleanroom is used, where contamination levels are low and where all processes are designed for wafer scale, although the device of interest only occupies an area of perhaps a few microns squared. We propose a low cost and more sustainable solution by bringing together all required process steps in a single tool. We chose a dual-beam instrument as a tool, as it already contains a focused electron beam and a focused ion beam, providing high-resolution imaging, ion milling, electron-beam lithography (EBL) and electron- and ion-beam induced deposition or etching (E(I)BID, E(I)BIE). The system we use is also standardly equipped with analysis tools such as Energy Dispersive X-ray (EDX) spectroscopy for compositional analysis, and in-situ Atomic Force Microscopy (AFM) for topographical analysis. In contrast to EBL, E(I)BID allows for 3D-nanofabrication as well (see Figure 1). As electron beam based techniques are serial writing techniques they are inherently slow. To enhance the speed in e-beam lithography and EBID(E) an add-on was designed and built that turns the SEM into a 25 beam tool. To allow for in-situ local sputter etching we developed a miniature DC plasma source that operates under SEM compatible vacuum conditions. An example of a circular hole etched into a gold layer is shown in Figure 2. Furthermore, a thermal evaporation source was miniaturized to enable the local deposition of metal layers. For in-situ atomic layer deposition (ALD) we developed our own substrate heater. By making use of Gas Injection Systems (GIS) with nozzles close to the device fabrication site, local ALD is achieved, and by using EBID seed layers also selective ALD is obtained[1]. To speed up the ALD cycles we adapted a GIS such that the pump-down time after a cycle is drastically reduced.

By combining all these techniques in a single instrument, functional devices can be made without having to break the vacuum, or to have access to a multi-million cleanroom. Figure 3 shows some example process flows for the in-situ fabrication of a complete device in our 'cleanroom in SEM'. This is still a work in progress, but we will discuss the instrumentation developed and show the results of the tests we have performed.

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[1] A.J.M. Mackus, J. J. L. Mulders, M. C. M. van de Sanden, W. M. M. Kessels, J. Appl. Phys. 107 (2010) 116102

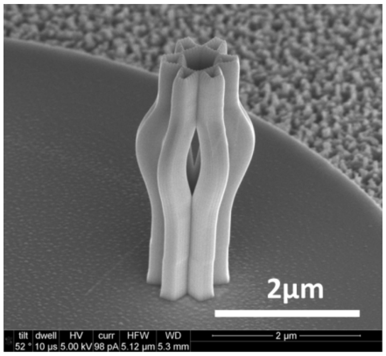

*Figure 1:*3D structure deposited using EBID from a $MeCpPtMe_3$ precursor.

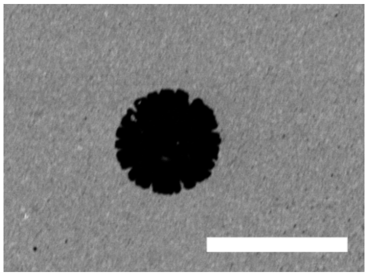

Figure 2: Secondary electron image of an area etched into a 200 nm thick gold layer on a silicon substrate by using a prototype Argon microplasma source. The scale bar is 10 µm.

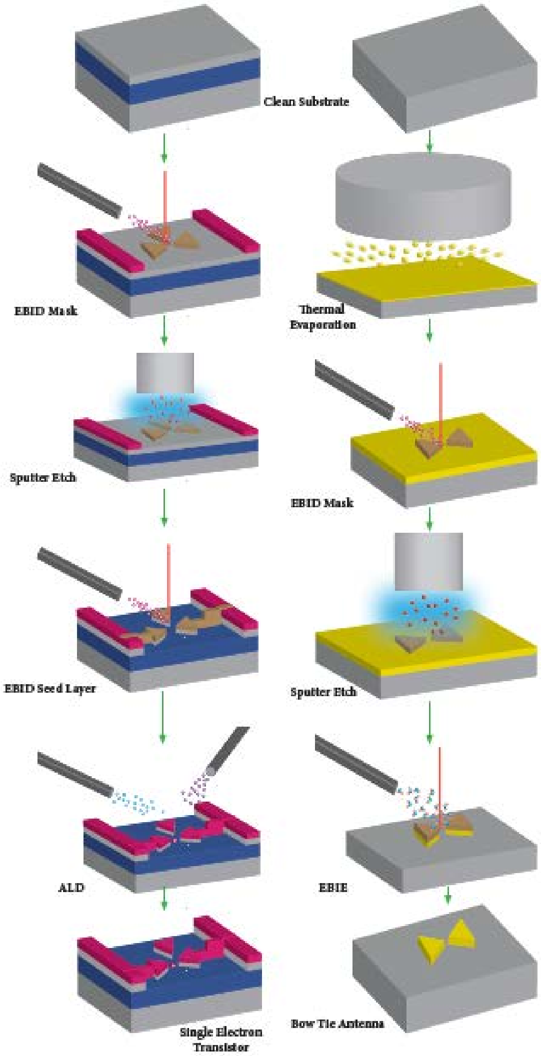

Figure 3: Example process flows in the 'Cleanroom in SEM' for in-situ device fabrication.