Electron-Beam-Induced Deposition of 3.5 nm Half-Pitch Dense Patterns on Bulk Si by using a Scanning Electron Microscope.

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Electron-Beam-Induced Deposition (EBID) is a direct deposition technique in which a focused electron beam dissociates precursor molecules adsorbed on a substrate surface. The minimum feature dimension possible with EBID is better than 1 nm, as has been demonstrated by using finely focused beams in Scanning Transmission Electron Microscopes[1]. For general acceptance of the EBID technique, however, it is beneficial to use the much more user friendly and widely spread platform of the Scanning Electron Microscope (SEM). In a SEM, some of us have previously demonstrated the deposition of 3 nm diameter dots using thin membranes as a substrate, to allow for transmission mode imaging[2]. The challenge we address here is to deposit such small structures on bulk substrates and use secondary electron imaging for inspection. Furthermore, we show that we can deposit dense lines and spaces, as required for the fabrication of complex devices such as integrated circuits.

In Figure 1, we show a nested–L shape, including two isolated lines, deposited from the platinum precursor $MeCpPtMe_3$ on a bulk Si substrate. This test is useful in judging control over linewidth and line spacing, and the potential presence of proximity effects. The deposition was done in an FEI Quanta 3D FEG Dual Beam machine, at 30 kV, spot 4, and beam current of 24 pA. The structure was written in 300 passes with a total dwell time per pixel of 600 μs. The total line dose was 1.2 mC/m. The lines have an average FWHM of 4.6 nm and a pitch of 9.8 nm, as measured from an integrated line profile across the lines. The good control that is obtained over the line width and spacing, and proximity effects, as is evident from the isolated lines having about the same width as the dense lines, was only obtained after optimizing the writing strategy. This required synchronization of the writing sequence with the 50 Hz line frequency, as well as a careful choice of: (1) the dwell time per pixel; (2) the number of passes; and (3) the waiting time between passes. We will discuss this optimization process in the presentation.

In figure 2 we show a deposited structure consisting of 4.4 nm dense lines, at a pitch of 6.9 nm, including contact lines to enable resistivity measurements of the deposited lines, and between adjacent lines. This demonstrates the potential of EBID to write actual devices and electrical test structures with sub-10 nm dimensions.

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[1] W.F. van Dorp, B. van Someren, C.W. Hagen, P. Kruit, and P.A. Crozier, Nanoletters 5, 1303 (2005).
[2] Leon van Kouwen, Aurelien Botman, and Cornelis W. Hagen, Nanoletters 9, 2149 (2009).

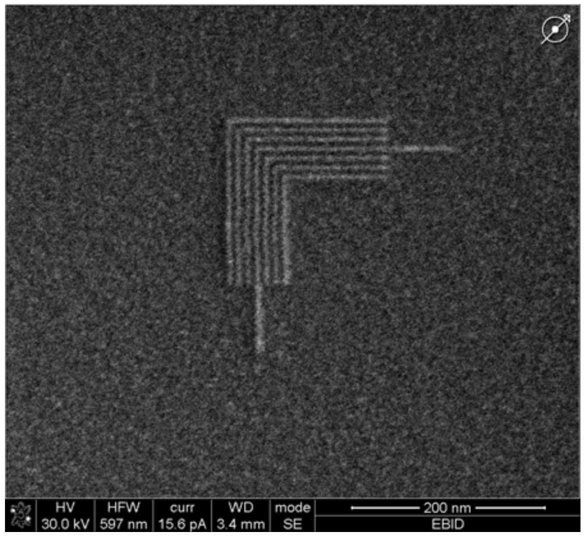

Figure 1: A nested L structure created with EBID on a silicon bulk substrate. The average FWHM of the lines is 4.6 nm at a pitch of 9.8 nm, as measured from an integrated line profile across the lines. The deposition was done in an FEI Quanta 3D FEG Dual Beam machine, at 30 kV, spot 4, and beam current of 24 pA. The structure was written in 300 passes with a total dwell time per pixel of 600 μs. The total line dose was 1.2 mC/m. Between the passes, a waiting time of 100 ms was implemented to give precursor molecules time to diffuse to depleted areas.

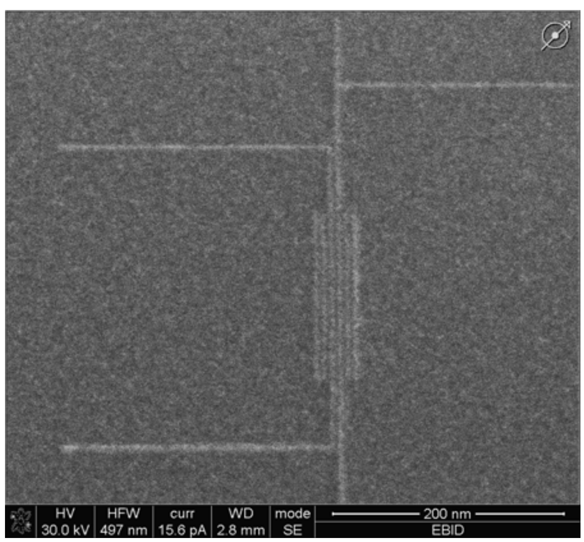

Figure 2: An electrical test structure created with EBID consisting of dense lines and spaces, with an average FWHM of 4.4 nm and a pitch of 6.9 nm, and isolated connection lines to enable resistivity measurements of the deposited lines, and between adjacent lines. The deposition was done in an FEI Quanta 3D FEG Dual Beam machine, at 30 kV, spot 4, and beam current of 24 pA. The structure was written in 500 passes with a total dwell time per pixel of 500 μs. The total line dose was 0.96 mC/m. Between the passes a waiting time of 100 ms was implemented to give precursor molecules time to diffuse to depleted areas.