1 nm patterning

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Electron-beam-induced deposition (EBID) is a versatile, direct, and resistless fabrication technique. A precursor gas is admitted in the vacuum of an electron microscope, and adsorbed precursor molecules are dissociated by both the primary and the secondary electrons, leaving non-volatile parts behind on the sample (Figure 1). Different precursor gases allow to deposit Pt, W, Au, etc. The deposits usually contain a large percentage of carbon. The old-fashioned carbon contamination deposits in electron microscopes is also a form of EBID. To obtain the smallest possible deposits, we studied the electron-sample interaction and carefully tuned the process parameters. We performed EBID experiments in an environmental Scanning Transmission Electron Microscope (STEM) at a beam energy of 200 keV, a 0.3 nm probe and $W(CO)_6$ as a precursor gas. Typical precursor gas pressures during the deposition are 10^{-3} Torr, and to reduce contamination from the microscope the substrates are held at an elevated temperature of 100-150 ˚C. We deposited arrays of nanometer sized dots on various thin membranes (SiN, amorphous carbon, graphite). The imaging and monitoring of the growth were performed with the annular dark field (ADF) signal.

Structures as small as a few nanometers can be deposited with good dimensional control (figure 2). One of the conditions for obtaining these small structures is that they should not be too tall (aspect ratios below about 2) in order to prevent broadening from electron scattering in the structure itself. Structures with an average size as small as 1.0 nm have also been fabricated [1], but at this near-molecular level several kinds of non-linearities occur. For instance, when an array of deposits is created with a fixed dwell time, the amount of mass varies from deposit to deposit. This distribution of masses becomes relatively wider as the dwell time decreases and the deposits contain less material [2]. To understand these findings we studied the nucleation of the deposits (Figure 3). We have also tried to use the ADF signal to control the deposition such that the beam is blanked after a preset amount of mass has been deposited (Figure 4).

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[1] W.F. van Dorp, B. van Someren, C.W. Hagen, P. Kruit, P.A. Crozier, Nano. Lett. 5 (2005) 1303
[2] W.F. van Dorp, B. van Someren, C.W. Hagen, P. Kruit, P.A. Crozier, J Vac Sci Technol B 24 (2006) 618

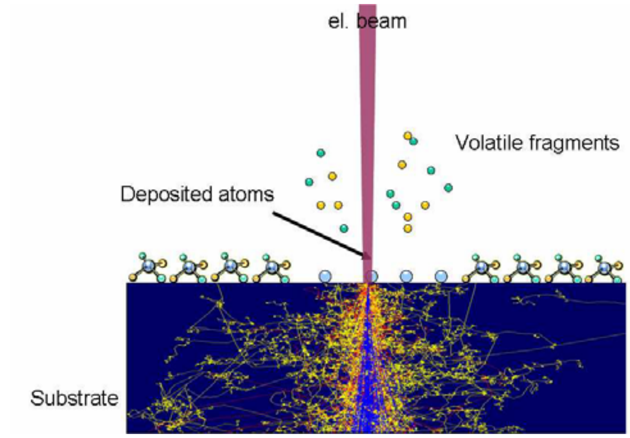

Fig.1: The principle of EBID

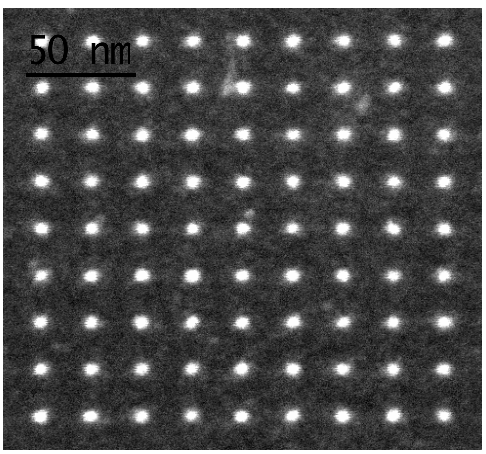

Fig.2: 4.5 nm diameter W dots on C foil at 11 nm half pitch

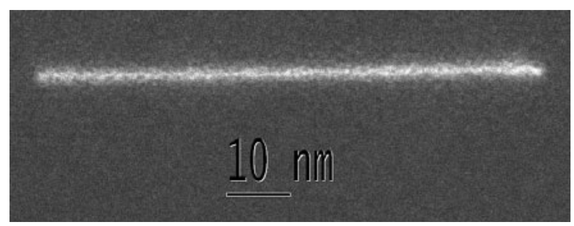

Fig.4: 1.8 nm linewidth FWHM

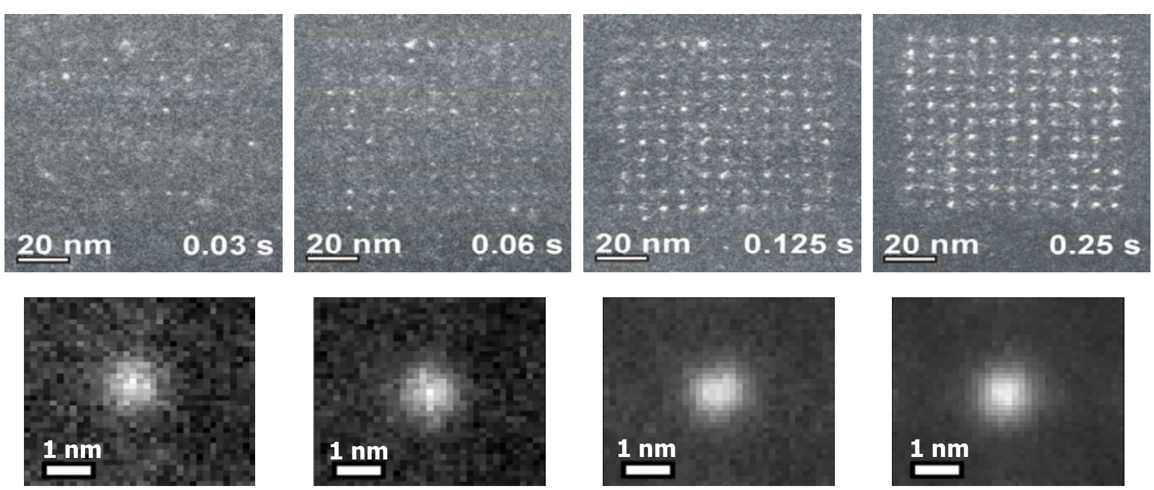

Fig.3: Through-dose series of 1 nm dots, both showing the resolution capabilities of EBID and the intrinsic limitation by the fluctuations in number of deposited molecules.