2-20 nm Lithography With Electron Beam Induced Deposition

C.W. Hagen [1*], W.F. van Dorp [1], M.J. van Bruggen [1], B. van Someren [1], P. Kruit [1], and P.A. Crozier [2]

[1] Applied Sciences, Delft University of Technology, Lorentzweg 1, 2628 CJ Delft, The Netherlands
[2] Center for Solid State Science, Arizona State University, Tempe, Arizona 85287, USA
[*] *e-mail: C.W.Hagen@tudelft.nl*

Introduction

In nanoscience an increasing interest exists in structures of sizes ranging from 20 nm down to 2 nm. For instance, one could think of electrical contacts to single molecules or the controlled fabrication of catalyst particles of a precise nanometric size. The most obvious lithography method to define such patterns is resist-based electron beam lithography. However the present resolution record with this technique is 6 nm. In addition to that, resist-based lithography processes always consist of many process steps and are usually limited to patterning on flat surfaces only. Electron Beam Induced Deposition (EBID) is a technique which does not have these disadvantages. In EBID an electron beam induces the dissociation of precursor molecules adsorbed at a substrate surface, resulting in a solid deposit on the surface and volatile precursor fragments which can be pumped away. However, until recently, it was believed that the resolution of EBID was not much better than 15-20 nm, although the electron beam used was as small as 1 nm. We were able to explain this [1] by analyzing the role of the secondary electrons in the deposition process and subsequently demonstrated that structures below 5 nm wide can be written if the deposition process is stopped in a very early stage.

Results of sub-10 nanometer fabrication.

We have performed nanofabrication experiments in a Tecnai environmental scanning transmission electron microscope (E-STEM), allowing the entire growth process to be controlled and observed in situ. The primary electron beam size was approximately 0.3 nm, and $W(CO)_6$ was taken as a precursor gas. Structures were fabricated on thin (10 or 30 nm thick, carbon or Si_3N_4) electron-transparent membranes.
We have deposited arrays of sub-5 nm dots (Fig. 1a). The smallest dots were written in a 10 by 10 array, with an average full width at half maximum of 1.0 nm (Fig. 1b) [2]. Although the electron beam dwell time to grow a dot was equal for each dot, a variation in deposited mass was observed, which is consistent with the Poisson statistics of the deposition process. By recording the time variation of the dark field current during deposition more insight is gained in the statistical nature of the growth process. Using this signal the deposition may be controlled such that structures even smaller than 1 nanometer can be obtained.

Instrumentation for a dedicated EBID lithography tool.

To develop EBID into a viable lithography technique one has to increase the fabrication speed. One way of doing that is by writing with many beams in parallel. We are developing a dedicated EBID system based on a Scanning Electron Microscope (SEM), but equipped with a novel Multi-Beam electron Source (MBS). The system is designed for 100 beams, each focused into a 1 nm spot with 25 pA of current at 30 kV (Fig. 2). This is achieved by dividing the emission current from a single Schottky thermal field emitter into 100 beams, each with its own microfabricated optics (Fig. 3) and blanking deflectors, such that all beams simultaneously can be focused onto a wafer using the standard SEM optical column [3], but each beamlet can be blanked individually.

In the lecture I will address these issues in detail.

References

[1] N. Silvis-Cividjian, C.W. Hagen, P. Kruit, M.A.J. van der Stam, H.B. Groen, Appl. Phys. Lett. 82 (2003) 3514-3516
[2] W.F. van Dorp, B. van Someren, C.W. Hagen, P. Kruit, P.A. Crozier, Nano Lett. 5 (2005) 1303-1307
[3] M.J. van Bruggen, B. van Someren, P. Kruit, Scanning 28 (2006) 42

KEYNOTES

Figures

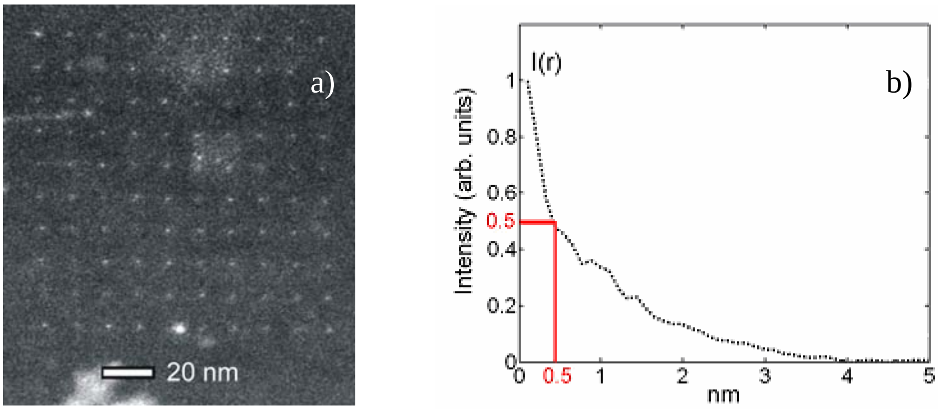

Fig. 1. a) a 10 by 10 array of dots, deposited from $W(CO)_6$. b): average radial intensity profile, showing a full width at half maximum of 1.0 nm.

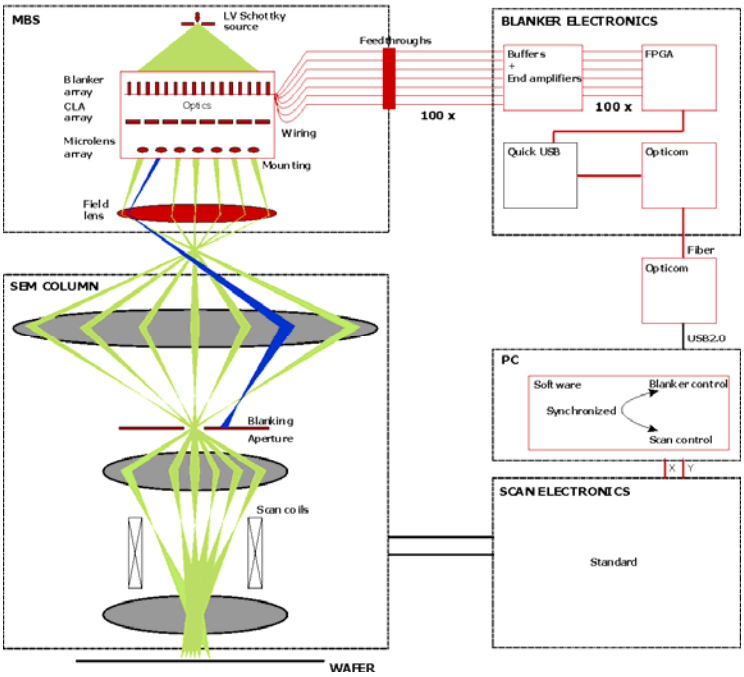

Fig. 2 Schematic overview of the Multi-beam SEM indicating the MBS unit, SEM column and the hardware necessary for synchronizing scanning and blanking.

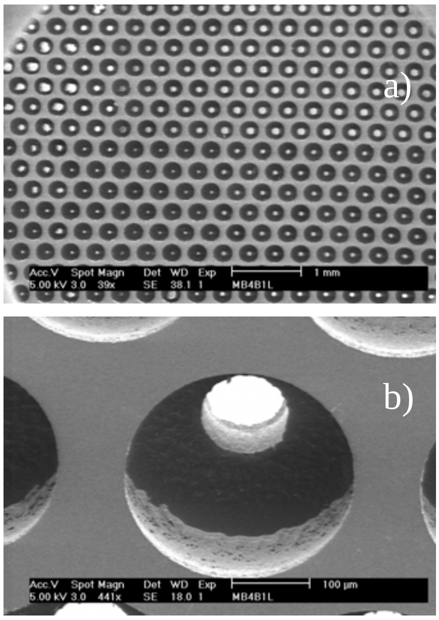

Fig. 3 SEM pictures of a silicon aperture plate. a) hexagonal array of 300 µm diameter lens apertures at 400 µm pitch and current limiting apertures ranging from 30-90 µm in diameter.

b) Close up of a lens hole with the current limiting aperture directly behind it.