3D-nanoprinting using Electron Beam Induced Deposition

N. Noordzij and C.W. Hagen

Department of Imaging Physics, Delft University of Technology, Delft, Lorentzweg 1, 2628CJ, Delft, The Netherlands
C.W.Hagen@tudelft.nl

Electron Beam Induced Deposition (EBID) is a single-step lithography technique that allows direct deposition of 3D-structures, similar to Ion Beam Induced Deposition (IBID). The latter has been used quite frequently for 3D structure fabrication, but, although some 3D structures, such as plasmonic helices[1] and even some more complex geometrical shapes[2], were recently reported, the potential of EBID as a 3D-nanoprinting technique has not yet been fully explored. Researchers have mostly taken an experimental approach to determine deposition parameters like dwell time, pitch, and precursor flux, but also an attempt was made to create a simulation model to guide the structure fabrication (ref. 1). Inspired by their work we have attempted to reproduce and elaborate on some of these structures to assess whether it is possible to write any arbitrary structure. These initial experiments raise some interesting questions about the kind of structures that can be written with EBID and suggest some areas for which more understanding is needed.
All structures were deposited on a Si substrate using the $MeCpPtMe_3$ precursor, in an FEI NovaNanoLab 650 SEM, at 5 keV, 98 pA, and a pressure between $9 \cdot 10^{-6}$ and $2 \cdot 10^{-5}$ mbar during deposition. It is assumed that an increasing dwell-time-per-pixel results in an increasing vertical growth-component. We noticed that for taller structures the growth decreases approximately linearly with height and that was compensated for by a linear increase in dwell time. We distinguish 3 types of structures. i) single open ended structures, such as the serially written vertical and slanted pillars and spirals in Fig. 1a resp. 1b. These structures are heavily deformed as a result of proximity effects. ii) semi-open ended structures, such as the fence-like structure and open mesh block in Fig. 1c resp. 1d. The geometry of the outer edges is seen to differ significantly from the internal connected structure, which may hint at the importance of precursor supply by surface diffusion. iii) closed mesh-like structures, such as in Fig. 1e and 1f, showing that the deformation due to proximity effects in helical structures and the geometry dependence of pillar growth rate at the open ends of semi-open ended structures can be circumvented by redesigning, or combining these structures to form closed symmetric structures.
We will present an overview of undesired effects encountered in 3D-EBID and discuss whether these are fundamental or can be compensated for by a better understanding of these effects and clever writing strategies.

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[1] M. Esposito et al., ACS Photonics 2 (2015) 105
[2] J.D. Fowlkes et al., ACS Nano 10 (2016) 6163

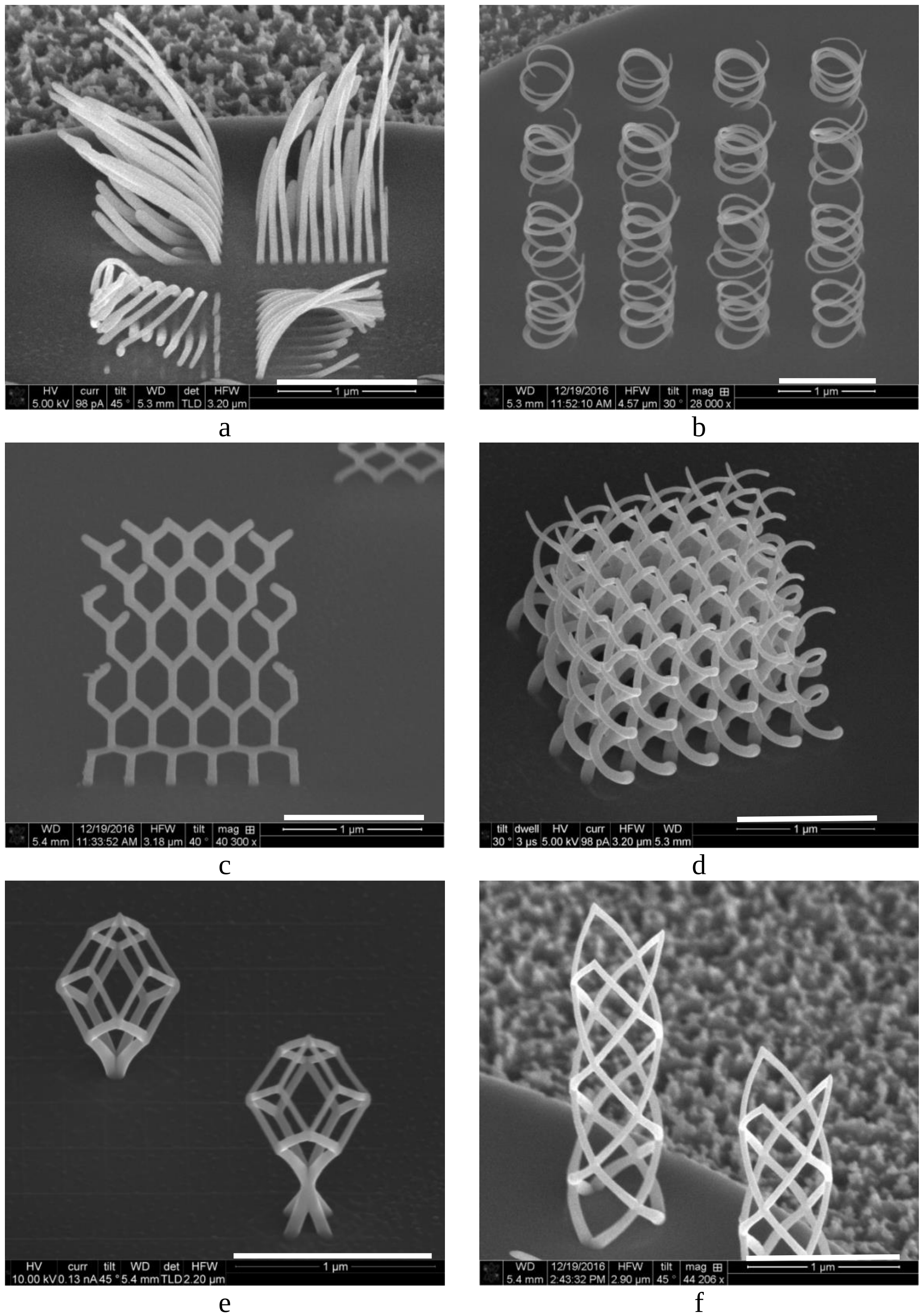

Figure 1: Three types of 3D-EBID structures are shown: single open ended structures (a, b), semi-open ended structures (c, d), and closed mesh-like structures (e, f), showing an increasing degree of structural integrity from top to bottom. The scale bar equals 1 μm in all figures.