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High-Precision 3D-Nanoprinting for Sheet-like Structures via FEBID

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Among the few additive-manufacturing techniques capable of creating 3-dimensional objects on the nanoscale, 3D nanoprinting via Focused Electron Beam Induced Deposition (3D-FEBID) is an increasingly relevant technology for building high-fidelity nanostructures. Its capabilities of depositing feature sizes below 20 nm under optimized conditions and below 100 nm on a regular basis and its flexibility both in terms of substrate as well as precursor materials make it a unique technology with many possibilities and yet unexplored applications. While it has been used and developed further for a few years now, most fabricated structures in the past have been meshed [1], meaning a combination of differently oriented, individual nanowires, connected at specific points in 3D space according to the target application. This work leverages 3D-FEBID to the next level by expanding its capabilities from mesh-like towards closed (sheet-like) structures with a high degree of precision. The main challenge and source of most deviations from target shapes is thereby based on local beam heating and its implications on local growth rates. While well-understood in meshed structures, closed objects revealed additional dependencies on the dimensions of built objects and the XY pixel position within the structures. Furthermore, electron trajectories are more complex in closed objects, introducing additional proximity effects. To address these problems, we combined finite-difference simulations with 3D-FEBID experiments and developed a Python-based compensation tool, capable of stabilizing the growth for each XY pixel point in individual patterning planes by pre-determined parameter adjustments (Fig. 1a). The gained insight allowed further expansion, now being applicable for different element widths and -heights, as demonstrated by more advanced structures (Fig. 1b). In a last step we introduced trapezoid and inclined elements into our compensation code (Fig. 2a), which we then combined to a "construction kit" tool that is able to build compound structures (Fig. 2b-d). By that, we crucially expanded FEBID-based 3D nanoprinting by opening up design possibilities for closed and consequently mixed objects for novel applications in various fields of research and development.

[1] R. Winkler et al.; 3D nanoprinting via focused electron beams; Journal of Applied Physics 125 (**2019**), 210901.

[2] A. Weitzer et al.; Expanding FEBID-Based 3D-Nanoprinting toward Closed High-Fidelity Nanoarchitectures; ACS Applied Electronic Materials, 4 (2) (**2022**), 744.

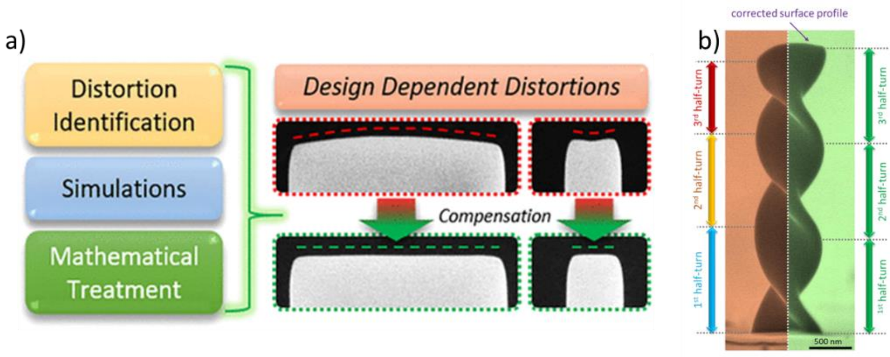

Fig. 1: Improvements due to our compensation tool on the example of (a) walls and (b) a screw [2].

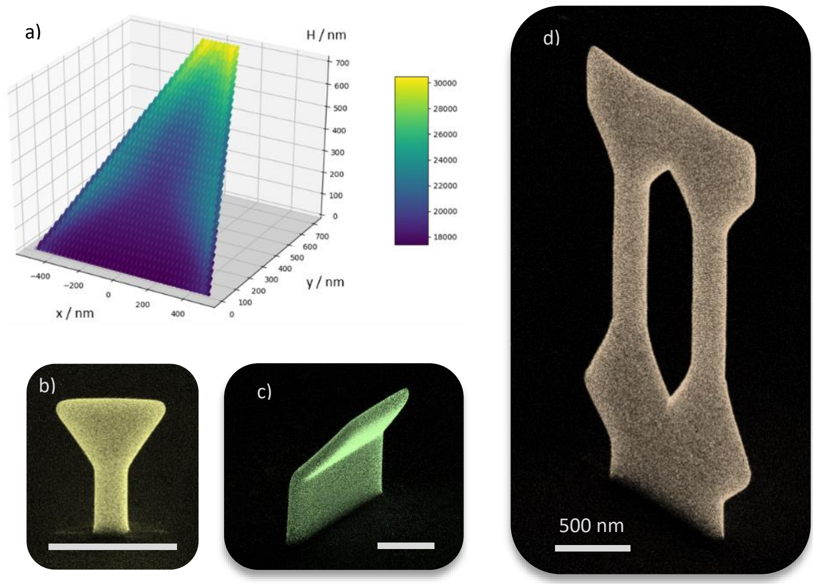

Fig. 2: Python compensation tool extensions for advanced FEBIP structures with (a) an illustration of the dwell time adjustments for a trapezoid structure and (b)-(d) SEM images of compound architectures.