P35: High Precision 3D Nanoprinting of Sheet-like Structures and their Controlled Spatial Bending via Electron Beam Curing

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3D printing via Focused Electron Beam Induced Deposition (3D-FEBID) is one of the very few additive direct-write manufacturing techniques capable of creating highly precise 3-dimensional structures at the nanoscale. While sub-100 nm features can be done on a regular basis with high design flexibility and varying precursor materials, optimized conditions enable structural elements down to the sub-20 nm regime. This technique is meanwhile well-established for mesh-like architectures [1], meaning individual nanowires, which are spatially connected in 3D space. The next logical step is the expansion from wires to sheet-like structures, to extend 3D design possibilities, as recently introduced [2].

One of the main reasons preventing a straight-forward deposition of high-fidelity FEBID sheets is local beam heating. This process strongly influences local growth rates, which, although well-understood for meshed structures, becomes a real challenge for sheet-like architectures of varying element widths. Thereby additional dependencies on the dimensions of built objects as well as on the XY pixel position within the structures arise. Furthermore, electron trajectories are more complex in sheet-like objects, introducing additional proximity effects. To minimize these shape-disrupting effects, we combined 3D
FEBID experiments with finite-difference simulations and developed a Python compensation tool. We were thereby able to stabilize the growth for each XY pixel point in all individual patterning planes by pre-determined parameter adjustments (Fig. 1a). We then expanded our compensation model to wards more advanced structures, such as vertical screws (Fig. 1b), inclined segments and non-rectan gular shapes like trapezoids. All improvements combined led to a “construction kit” tool that is able to build compound structures (Fig. 1c) with very high shape fidelity. We thereby crucially improved FEBID based 3D nanoprinting of closed and consequently mixed objects.

In a next step, we applied post-growth electron beam curing (EBC) [3] to sheet-like 3D objects, to evaluate, whether this approach opens up new possibilities. In the process, structures are again irradiated by electrons, this time, however, without precursor gas present and only at selected areas (Fig. 2a). This impacts the inner structure and thereby the overall volume of exposed regions and, if only applied partially, enables controlled bending deformations (Fig. 2b and c). To gain a greater insight on this manner we performed experimental series and analyzed the resulting structures via SEM, TEM and AFM. We complemented these investigations by Monte Carlo Simulations to explore and identify ideal parameters for smooth, stable and reproducible morphological bending. In our studies, we included a variety of parameters, such as primary electron energy, overall dose, point pitch, dwell time, and beam incidence angle to achieve controlled and reproducible results. The expansion to more complex EBC patterns allows sophisticated bending (Fig. 2d-f), which, beyond morphological implications, is useful for functional imprinting of varying material properties in EBC-treated regions. We thereby extended the post-growth treatment possibilities of FEBID, showing both, flexibility and impact of EBC.

With this combined approach of strongly improved high-precision 3D-FEBID and post-deposition shape adjustments, we were able to open up entirely new design and tuning possibilities for high-fidelity nanostructures, some of which clearly go beyond the capabilities of sole 3D-FEBID (e.g. Fig. 2f).

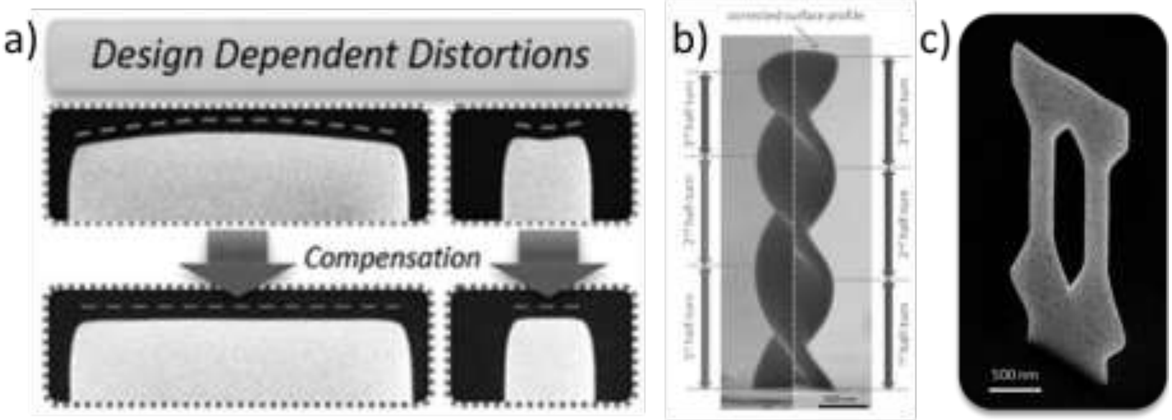

Figure 1: Strongly improved shape-accuracy during 3D-FEBID. (a) Comparison between directly deposited (top) and shape-stabilized wall elements (bottom). (b) Deposition of a twisted wall structure without (left) and with (right) height/temperature corrections. (c) Expansion of the developed compensation tool towards more complex structures with critical bottleneck features.

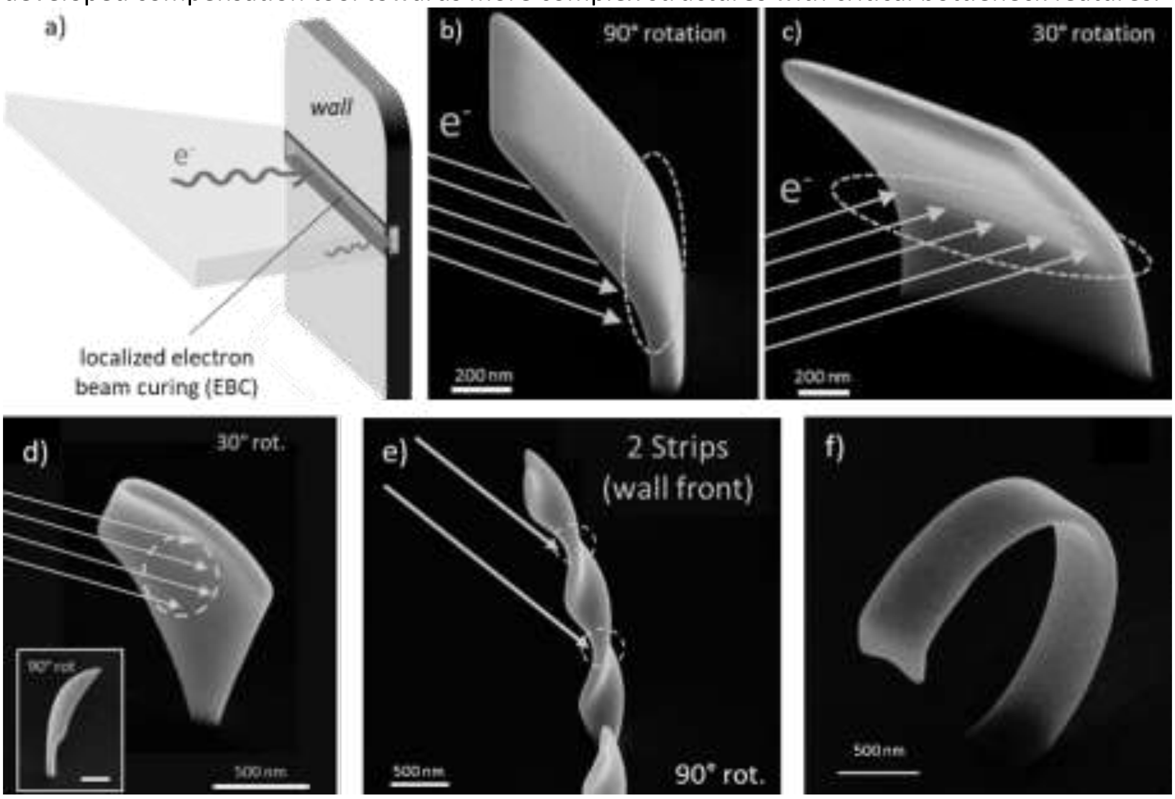

Figure 2: Controlled bending of 3D FEBID structures via EBC. (a) Schematic of the curing process with (b) and (c) the corresponding experimental results. (d)-(f) show more sophisticated deformation processes with (d) a sheet-like diamond element wrapping around a circular EBC area, (e) a screw bent at two curing sites and (f) where a complex overhanging structure was achieved.

References

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