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Using Electron Beam Curing (EBC) for the Controlled Bending of 3D-Nanoprinted FEBID Structures

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Additive manufacturing via Focused Electron Beam Induced Deposition (FEBID) is an increasingly relevant technique for depositing high-fidelity architectures on the nanoscale. While most such structures in the past were of a meshed nature [1], recent developments towards building closed (sheet-like) elements have opened up the field for a whole new range of possibilities [2]. In a next step we now explored post-growth electron beam curing (EBC) [3], where the structures are locally irradiated without precursor gas present. This process impacts the inner structure and the overall volume of exposed elements and, if only applied partially, enables controlled deformation. We therefore performed experimental series, analyzed via SEM and TEM and complemented by Monte Carlo Simulations to explore and identify ideal parameters for smooth, stable and reproducible morphological bending. Figures 1a and 1b show a vertical wall with a width of 1 µm and a height of 2 µm that was bent via electron beam irradiation within a defined area across the structure. Figure 1c shows a more complex (originally straight) screw element where two areas have been exposed to EBC, clearly illustrating the bending effect towards the incidence direction. We attribute this "forward" bending to smaller interaction volumes of the incoming electrons compared to the wall thickness, mainly influencing the front part of the elements in comparison with the back side. We evaluated the impact for a variety of parameters, such as voltage, point pitch, dwell time, overall dose and beam incidence angle to achieve controlled and reproducible results. The expansion to more complex EBC patterns leads furthermore to more sophisticated bending as will be presented as well (see Fig. 2). We thereby extended the post-growth treatment possibilities of FEBID, showing the flexibility of EBC for various applications in research and development, some of which clearly go beyond the capabilities of sole 3D FEBID (e.g. spatially tuned mechanics).

[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.

[3] F. Porrati et al.; Tuning the electrical conductivity of Pt-containing granular metals by postgrowth electron irradia-tion; Journal of Applied Physics 109 (**2011**), 063715.

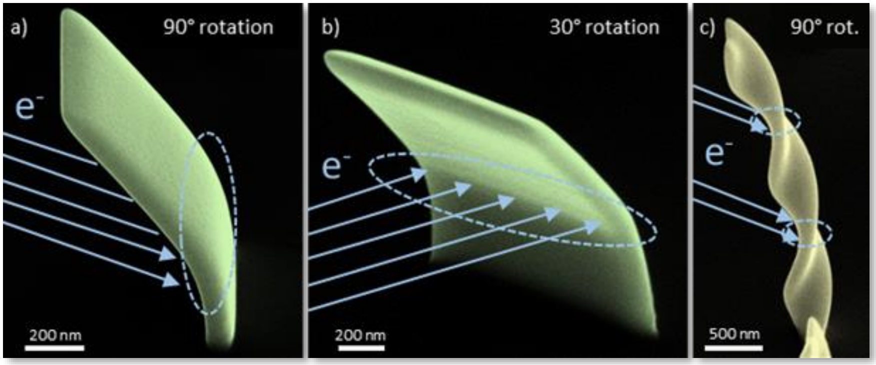

Fig. 1: Bending of sheet-like 3D FEBID elements. Bent wall from a side angle (a) and from a 30° rotated point of view (b) and twofold bent screw structure (c).

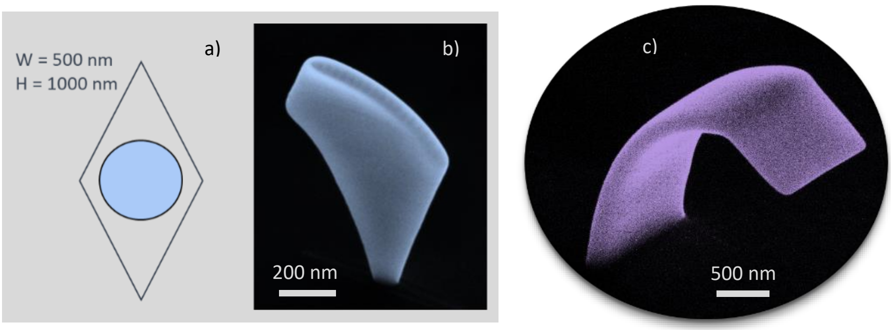

Fig. 2: More advanced electron beam curing with (a) a schematic for the bending of a diamond architecture via a circular curing pattern, (b) the corresponding SEM image of the real structure and (c) a wall element that was bent to an overhang.