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

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Introduction

In this work we explore post-growth **electron beam curing (EBC)**[1] without precursor gas for **closed, Pt-based FEBID structures**.[2,3] While EBC was mostly used for full area curing in the past, we here explore the possibilities of selected area EBC on freestanding 3D objects. This process impacts the inner structure and the volume of exposed regions, which enables controlled deformation. We therefore performed systematic experimental series, analyzed via SEM, TEM and AFM and complemented by Monte Carlo Simulations to identify ideal parameters for smooth, stable, reproducible and controlled morphological bending.

Experiments

When closed or mesh-like structures are locally irradiated by electrons with a fitting parameter set, targeted bending via EBC becomes possible, presumably due to structural and volumetric changes. Fig. 1 shows different angles of a wall that was built straight and was later exposed to a rectangular electron beam pattern (a, b), as well as a screw that was bent at two dedicated positions (c). The kink-like deformations are clearly visible, proving the working principle. To understand and optimize this process, different parameters were studied, such as primary electron energies (Fig. 2), overall doses (Fig. 3) and others (point pitch, dwell times, incidence angles etc.). For a wall thickness of ≈ 100 nm and a 52° incidence of the beam, the energy variation showed the strongest forward bending effect for ≈ 2 keV and the strongest backward bending for ≈ 20 keV. These results were compared to simulations, such as the one in Fig. 4, which illustrates the electron interaction volume via maximum penetration depths for a voltage of 2 keV. The strong concentration towards one wall side confirms our experimental findings. Details on the mentioned Monte Carlo simulations can be found in Fig. 6. These kinds of bending deformations are systematically applicable for different wall widths, as depicted in Fig. 5 for widths between W = 0 nm and W = 2000 nm. Small variations in the achieved bending angles are yet to be investigated in more detail.

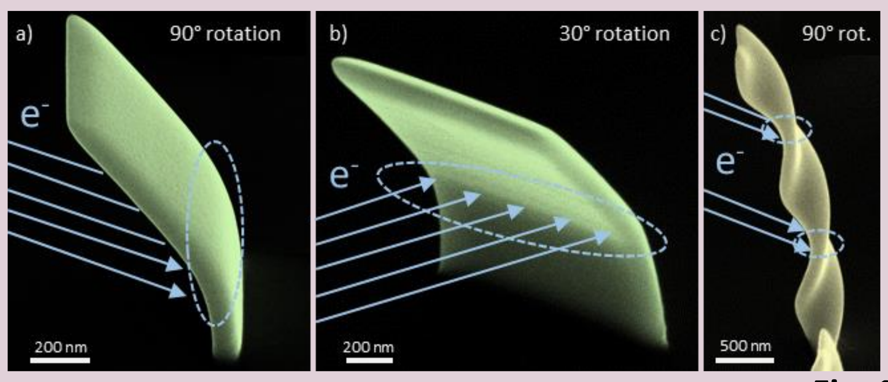

Fig. 1

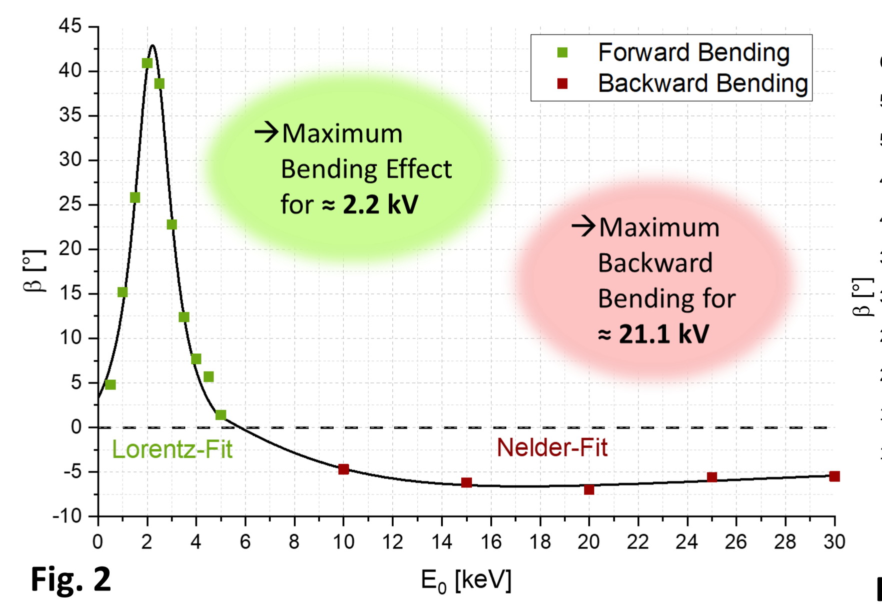

Fig. 2

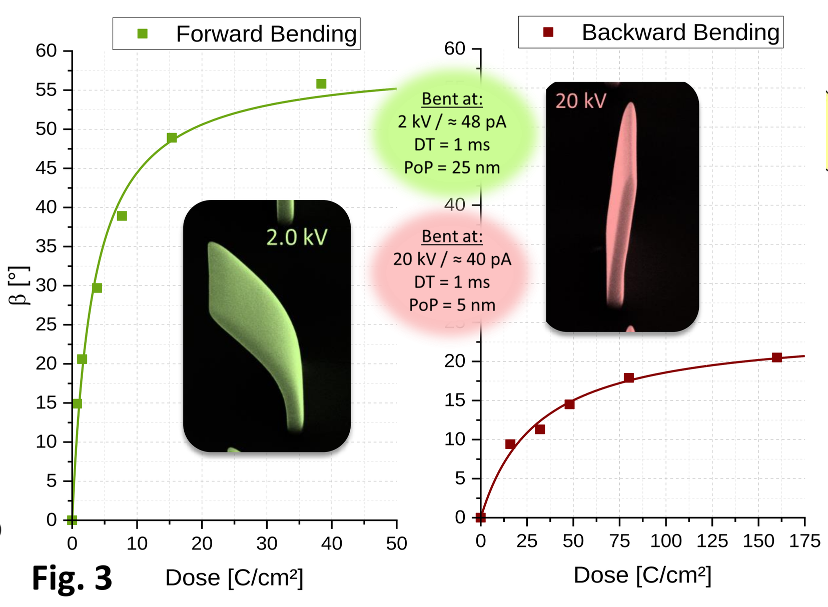

Fig. 3

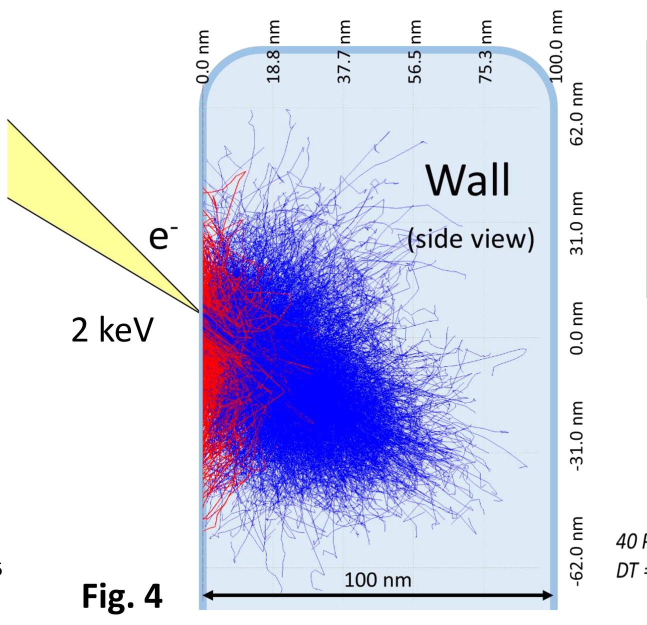

Fig. 4

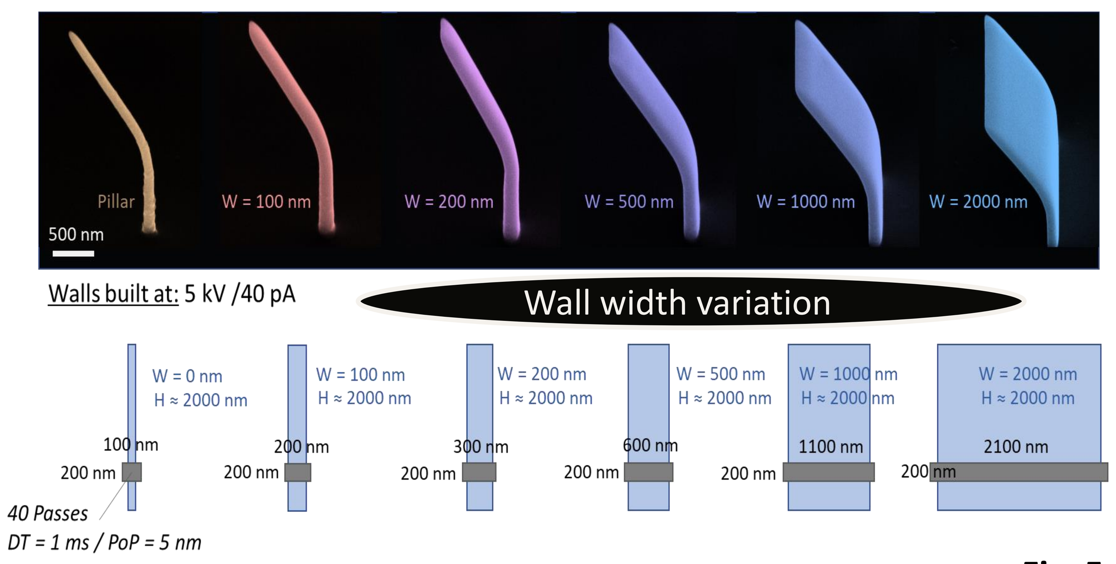

Fig. 5

Monte Carlo Simulations

Additional Monte Carlo simulations with Casino© validate our theory that bending is most effective if the majority of electrons impacts one half space of the exposed structure. This is shown in Fig. 6a by the energy dependent penetration depths together with Fig. 6c, which shows the ratio in the half-space pointing towards the incoming beam. Both findings are in agreement with the observation that E_0 around 2 keV are ideal settings for most efficient forward bending. Lower energies reduce the widths of the modified layer, resulting in less tensile stress and thus reduced bending. Higher energies distribute the effect along the entire width, again reducing the anticipated bending (see scheme below in Fig. 6b).

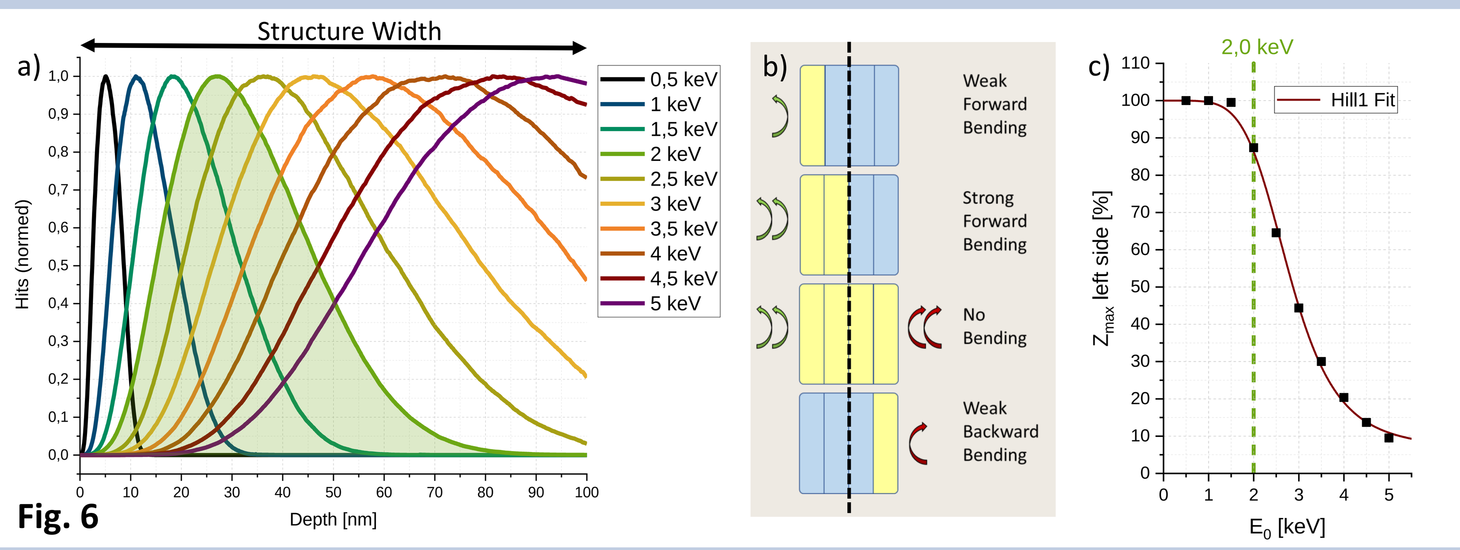

Fig. 6

Special Shapes, TEM- and AFM Measurements

Deforming closed FEBID structures with EBC is of course not only possible via horizontal rectangular electron beam patterning on walls but works for arbitrary shapes, some of which are shown in Fig. 1c (bent screw), Fig. 7a (diamond structure with circular curing pattern) and in Fig. 10 for a diving blade which was bent five times after deposition, producing an overhanging geometry. We thereby demonstrate, how this flexible approach could be used in a very target-oriented way to locally adapt existing FEBID structures. Additional TEM studies (Fig. 8) reveal the EBC impact as brighter regions in dark field images due to slightly increased Pt grain sizes and higher packing densities as a consequence of the proposed volume loss (compare Fig. 7d). We therefore suspect the interplay of reduced volume and altered inner structure to be responsible for the bending effect.

Complementary AFM investigations for a series of partially cured (rectangular patterns) horizontal walls provide proof for the suspected volume loss due to EBC (see Fig. 9)

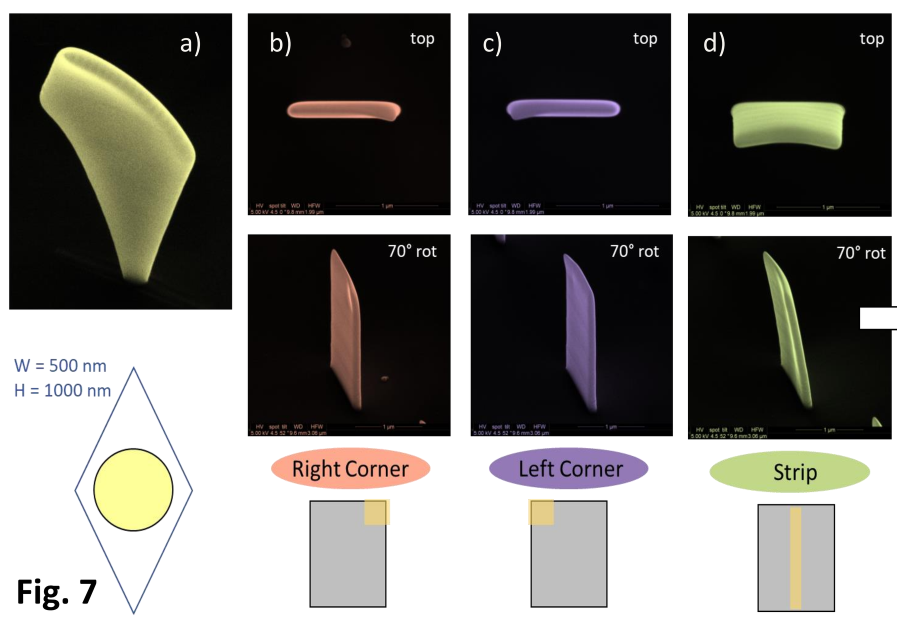

Fig. 7

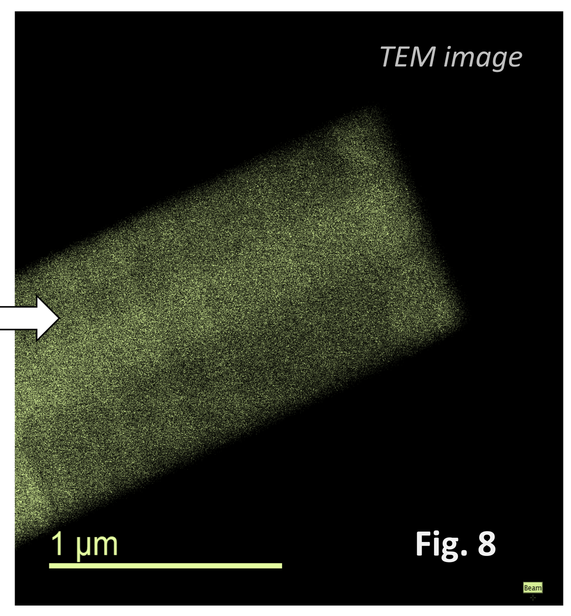

Fig. 8

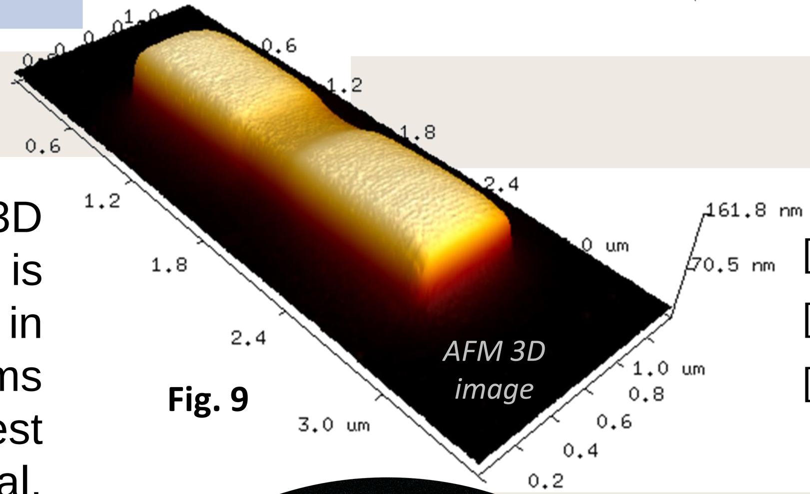

Fig. 9

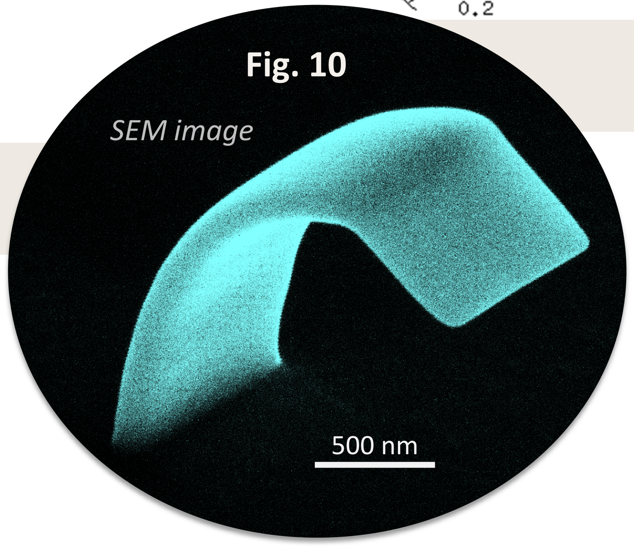

Fig. 10

Conclusion

We applied localized EBC as morphological tuning tool for pre-existing 3D FEBID objects. The study gives an insight into the mechanism, which is proposed as a combination of nano-grain growth and volume loss in agreement with experiments and simulations. While primarily used in terms of controlled morphological adaption, the structural changes also suggest the possibility of a localized, functional tuning tool concerning mechanical, electrical or even thermal properties.

Acknowledgements

Special thanks goes to the whole team at FELMI- ZFE for fruitful discussions and collaboration as well as to our financial partners.

References

[1] F. Porrati et al.; Journal of Applied Physics 109, 063715 (2011).
[2] R. Winkler et al.; Journal of Applied Physics 125, 210901 (2019).
[3] A. Weitzer et al.; ACS Applied Electronic Materials, 4 (2), 744 (2022).

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