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## Introduction

Nanostructures fabricated by Focused Ion/Electron Beam Induced deposition (FIBID/FEBID) can show different functionalities. However, in the as-deposited state, typically the materials contain a high percentage of impurities (mostly carbon, Fig.1), making them unattractive for many applications. However, various *post-processing approaches* allows to tune the material properties<sup>[1]</sup>.

Here, we focus on post-growth irradiation of the structures with *electrons* under

- Vacuum condition (Electron Beam Curing)
- Low-vacuum water atmosphere (Purification)

We demonstrate the *local application* of those approaches, denoted as „**Functional Imprinting**“

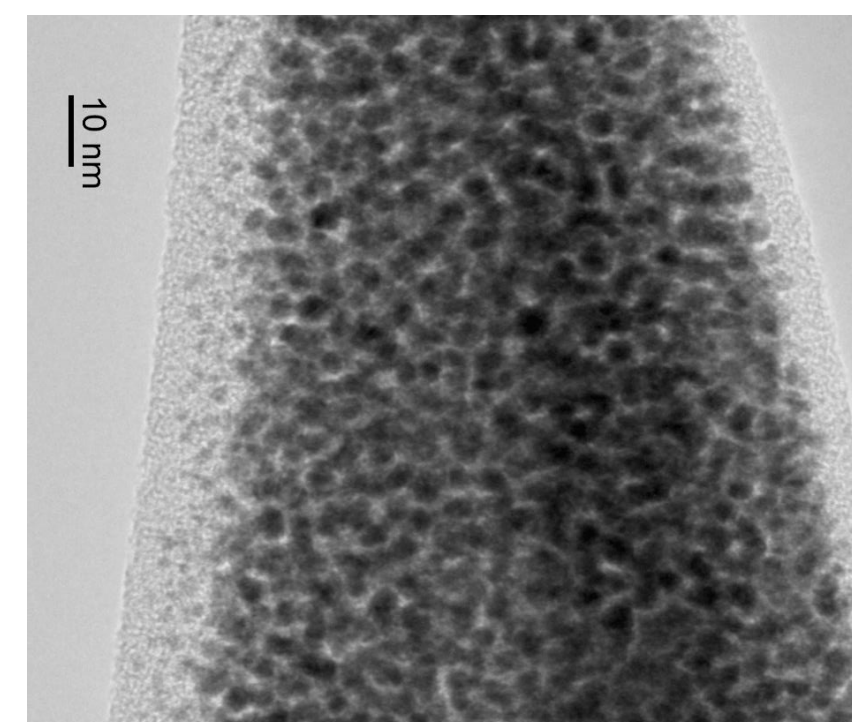


Figure 1: TEM image of an Au<sub>x</sub> pillar showing a nanogranular composition

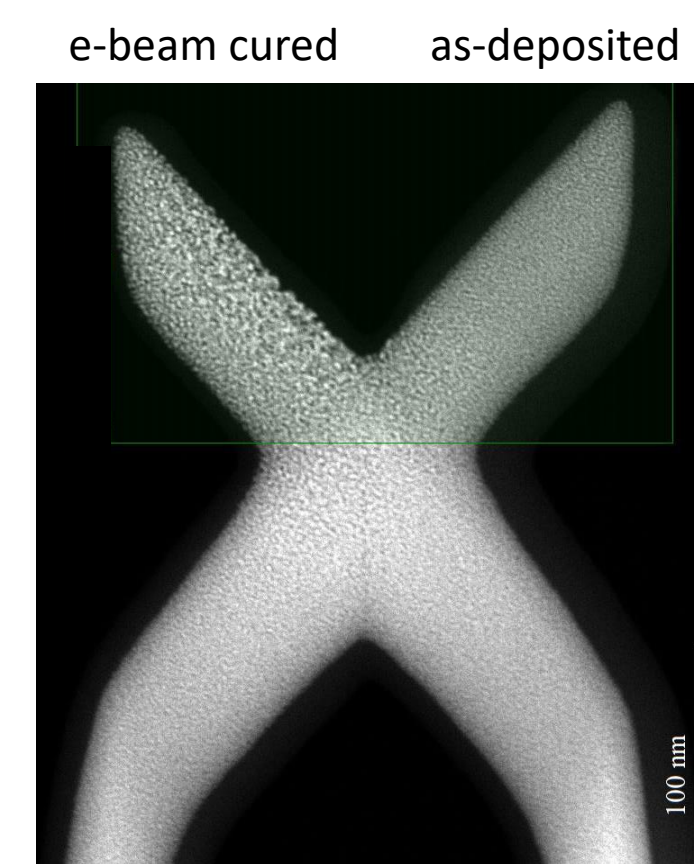
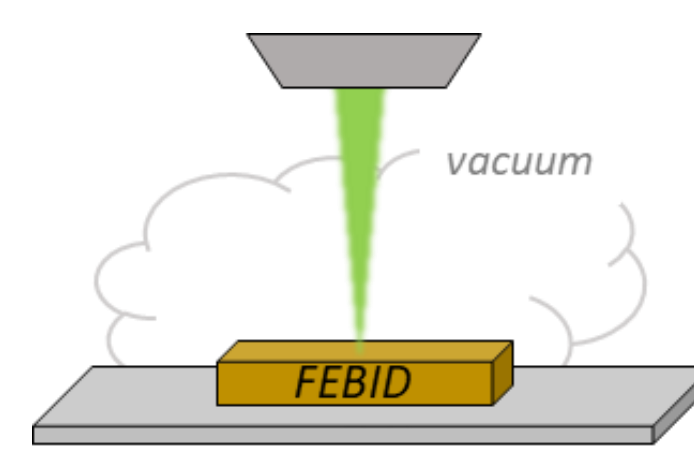


Figure 2: TEM image of a 3D-FEBID Pt<sub>x</sub> structure with one branch EBC.

## Electron Beam Curing

Electron Beam Curing (EBC) is the irradiation of FEBID/FIBID materials with further electrons.

- Further fragmentation of deposited precursor molecules
- Grain growth (Fig. 2, 3)
- Modification of the carbon matrix (Fig. 4)

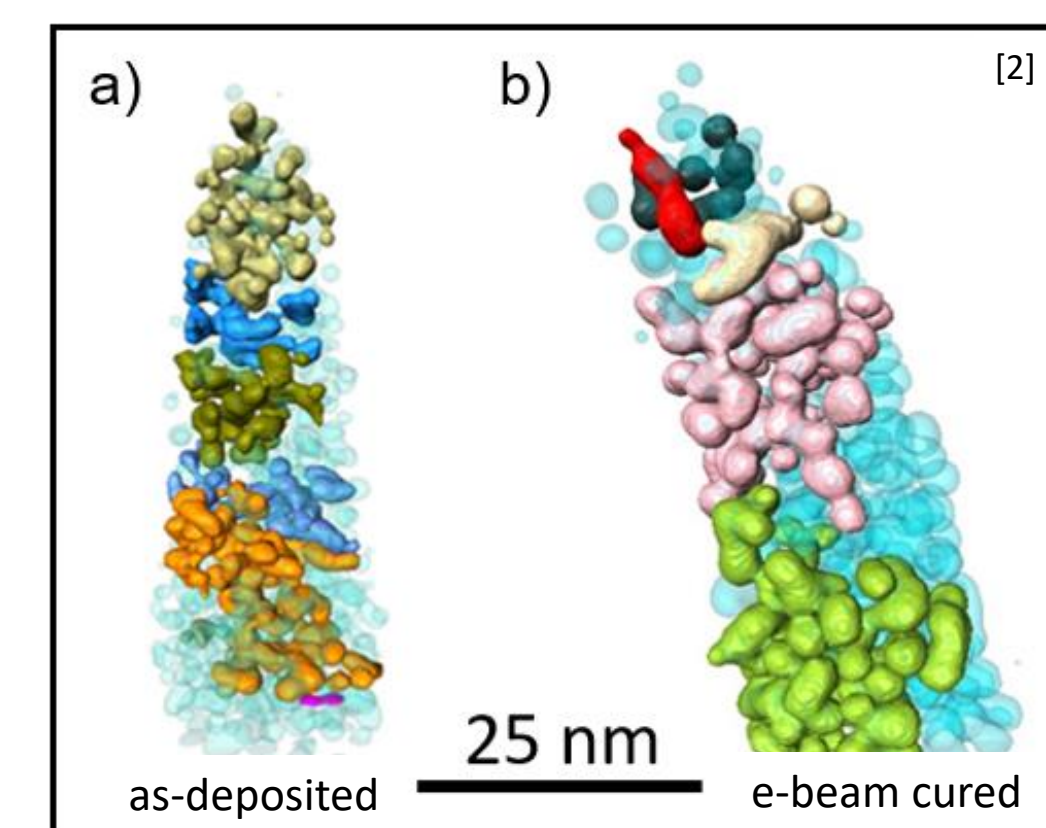


Figure 3: TEM Tomography of an as-deposited and cured Pt<sub>x</sub> pillar revealing growth of the metal grains.

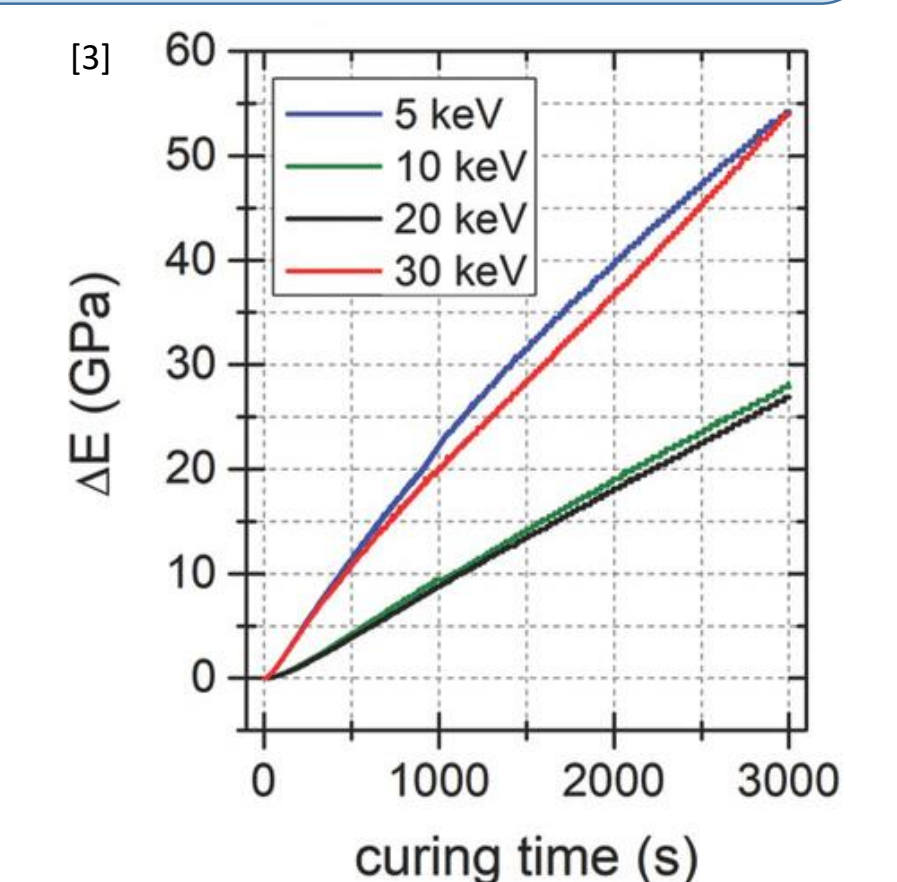
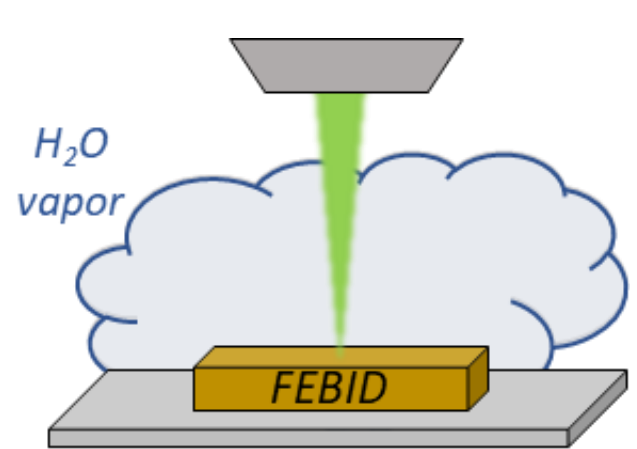


Figure 4: Increase of Young's modulus of FEBID-pillars (Pt<sub>x</sub>) with curing dose.

## Purification in Water Atmosphere



H<sub>2</sub>O purification is the irradiation of FEBID/FIBID materials in low-vacuum water vapor with further electrons.

- Carbon is efficiently removed (CH<sub>4</sub>, CO)
- The deposit shrinks in height, while the shape is widely maintained
- (Poly)-crystalline, carbon-free material
- Pore/crack – free
- Room temperature procedure

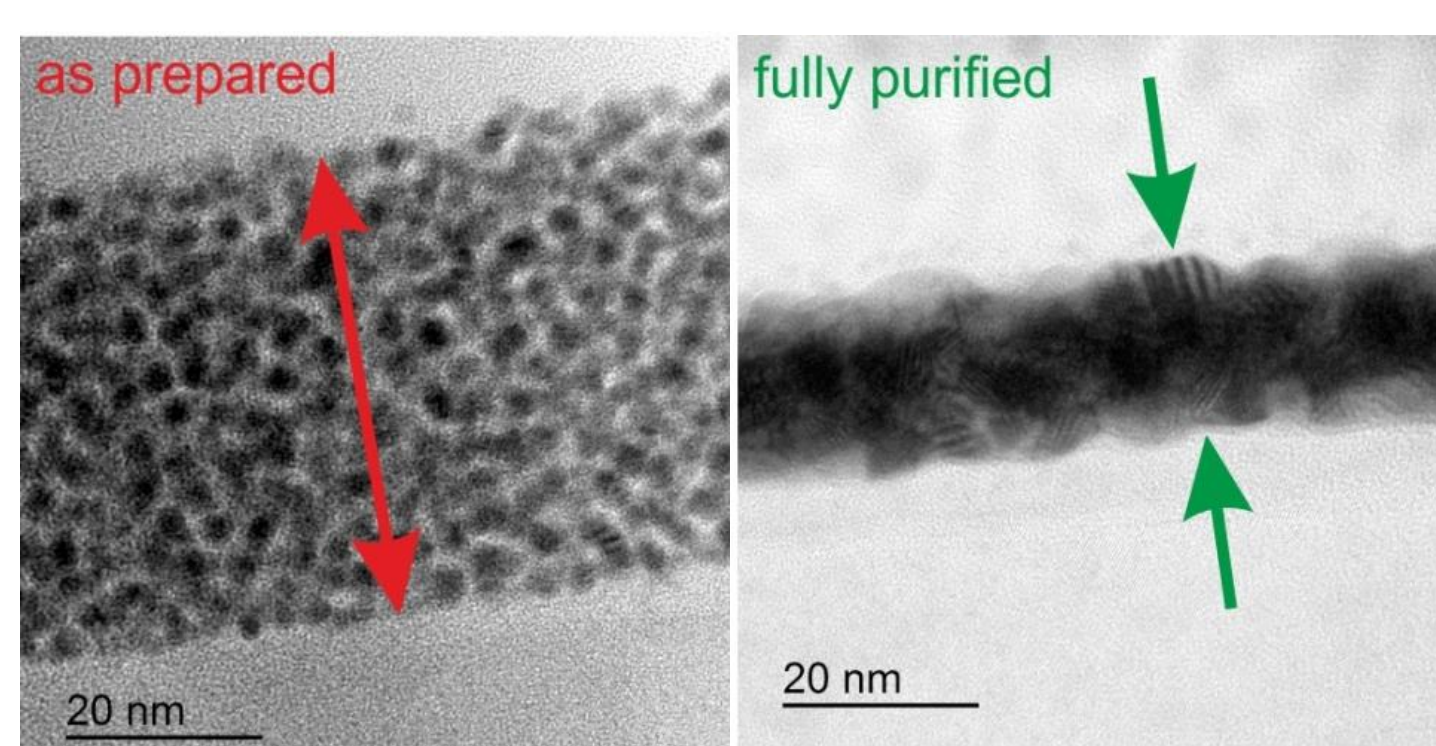
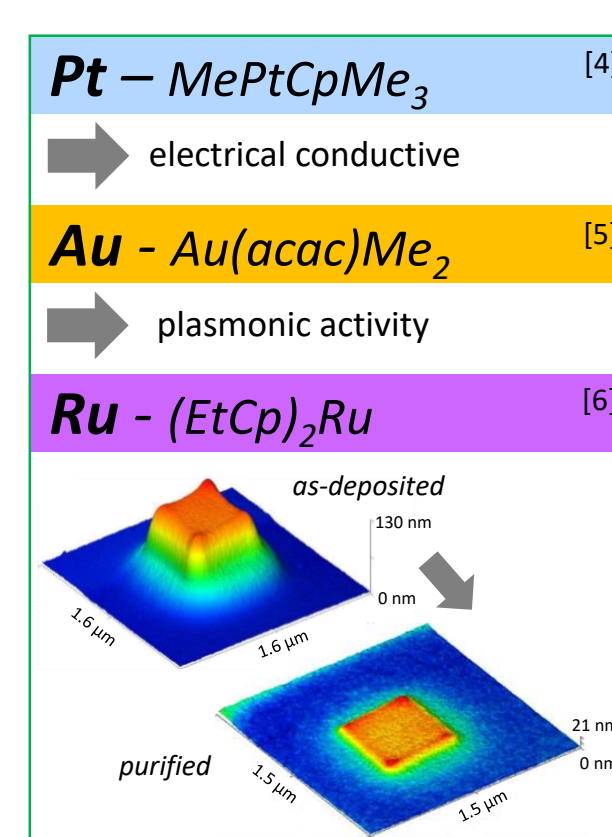


Figure 6: Comparison of Pt<sub>x</sub> microstructure in the as-prepared state and after fully purification shows a densification and large, closely packed platinum grains after the treatment.<sup>[4]</sup>

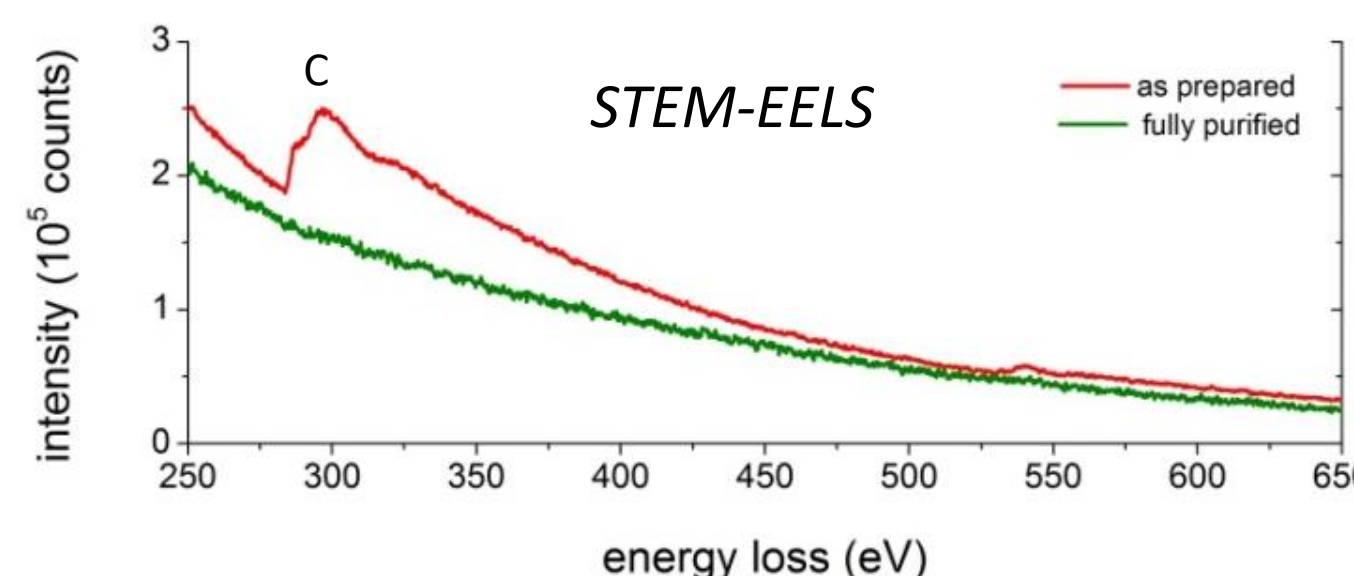
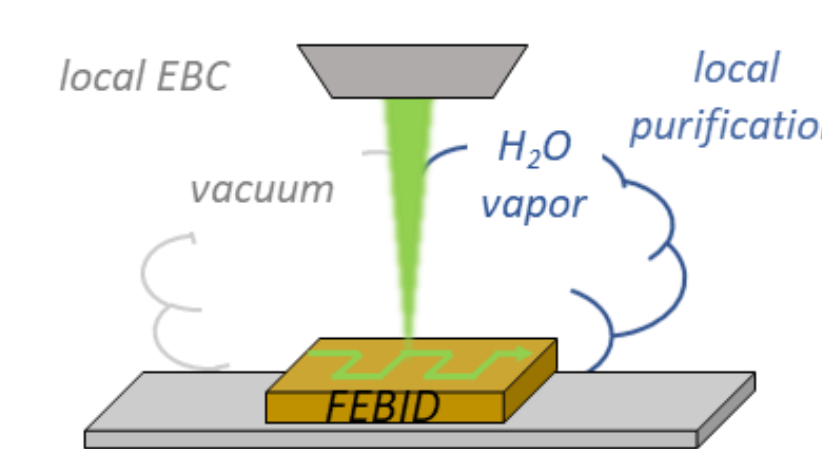


Figure 7: STEM-based Electron Energy Loss Spectroscopy confirms the removal of carbon.<sup>[4]</sup>

## Functional Imprinting



Functional imprinting is the local modification of FEBID/FIBID materials by either E-Beam curing, or purification in water atmosphere.

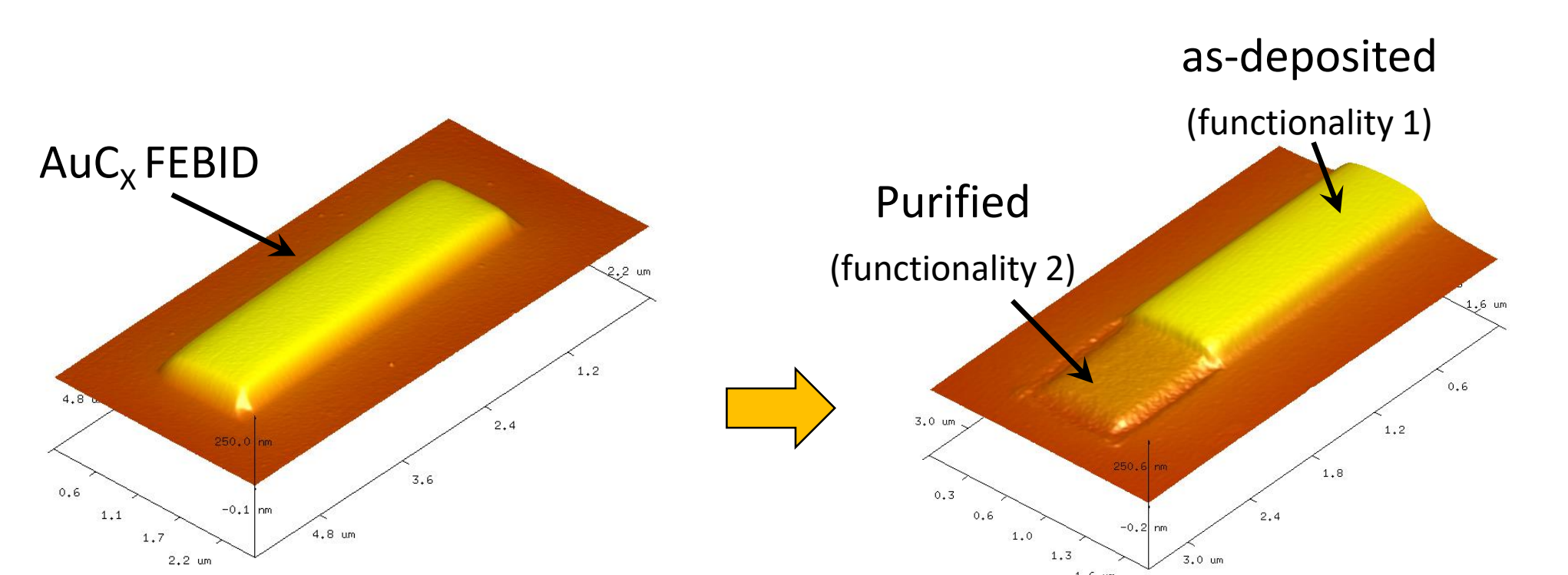
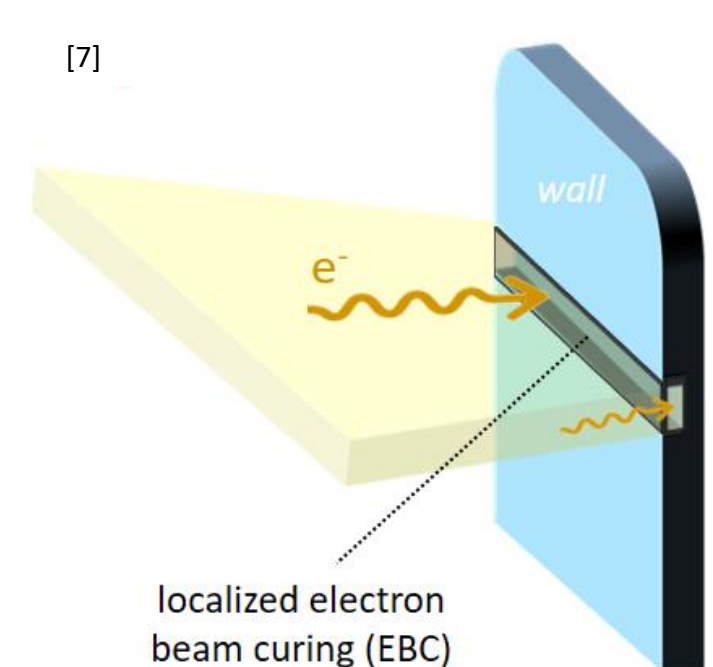


Figure 8: AFM image showing that the as-deposited material is used as scaffold to imprint areas of different functionality (pure gold areas).

## Functional Imprinting – Electron Beam Curing



Freestanding Pt<sub>x</sub> FEBID walls have been deposited (5 keV/40 pA) and subjected to local E-Beam Curing.

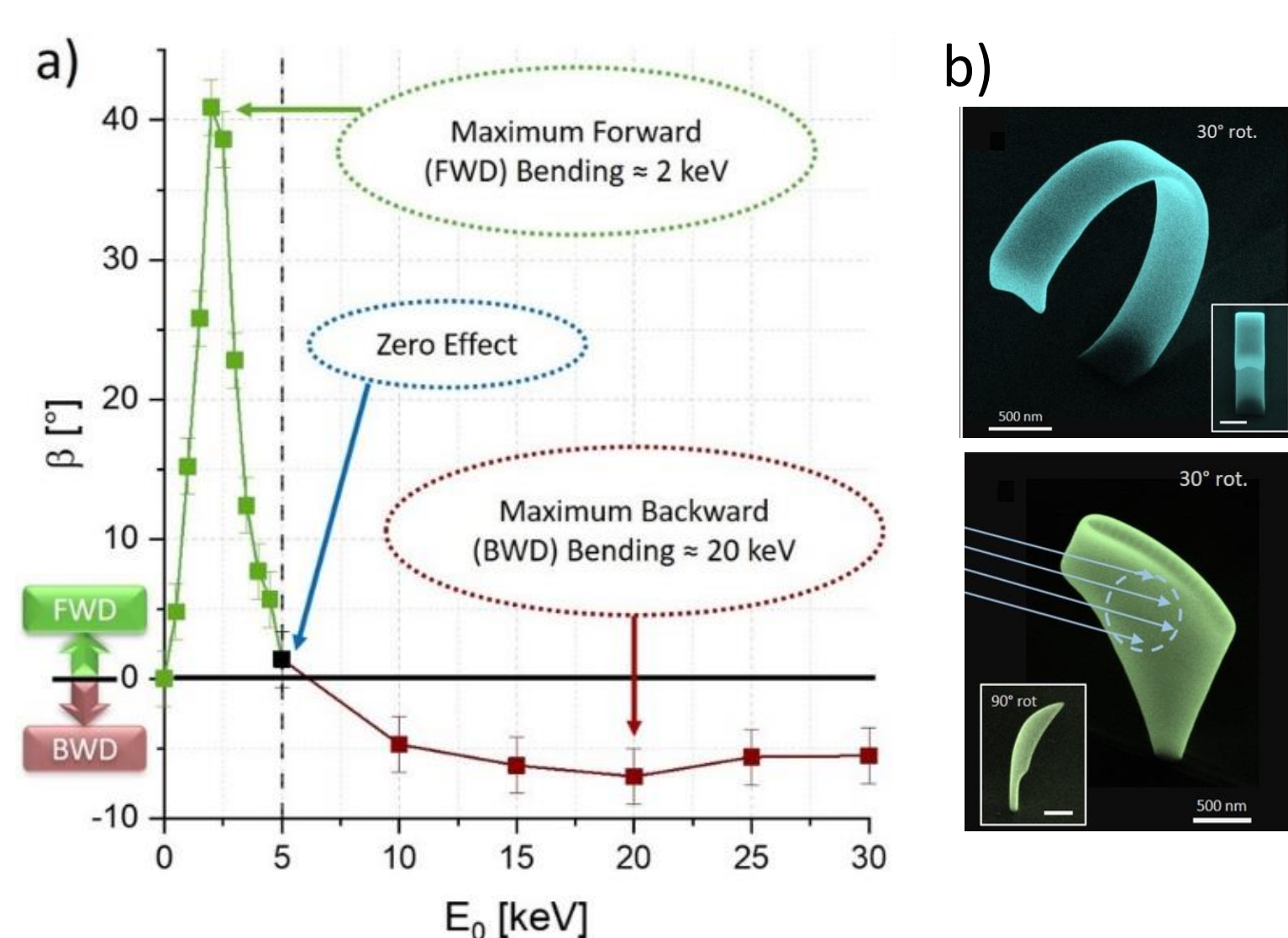


Figure 9: (a) Electron beam curing leads to a bending of the wall at the area of exposure. While for low energies the wall is bending towards the incoming beam, for electron beam energies larger than 5 keV, a backward bending is observed. (b) Examples of controlled bending of closed FEBID structures, which can not be fabricated directly by FEBID/FIBID.<sup>[7]</sup>

## Functional Imprinting – Local Purification

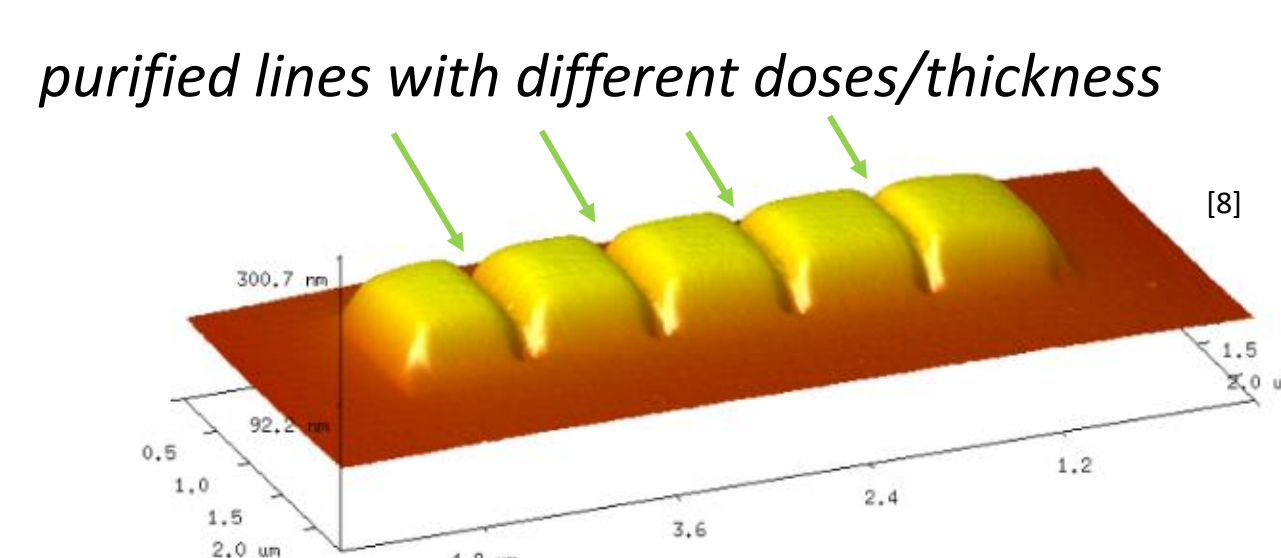


Figure 10: AFM image of an Au<sub>x</sub> rectangle that has been deposited and purified at the indicated locations using different thicknesses and electron doses. The significant volume loss is clearly visible.<sup>[8]</sup>

To answer questions about  
(1) *crystallinity and grain sizes*  
(2) *chemistry and carbon contents*  
(3) possible *resolution* of the imprint  
a TEM lamella was prepared from the cross-section.

### Crystallinity

- Highly crystalline in purified areas

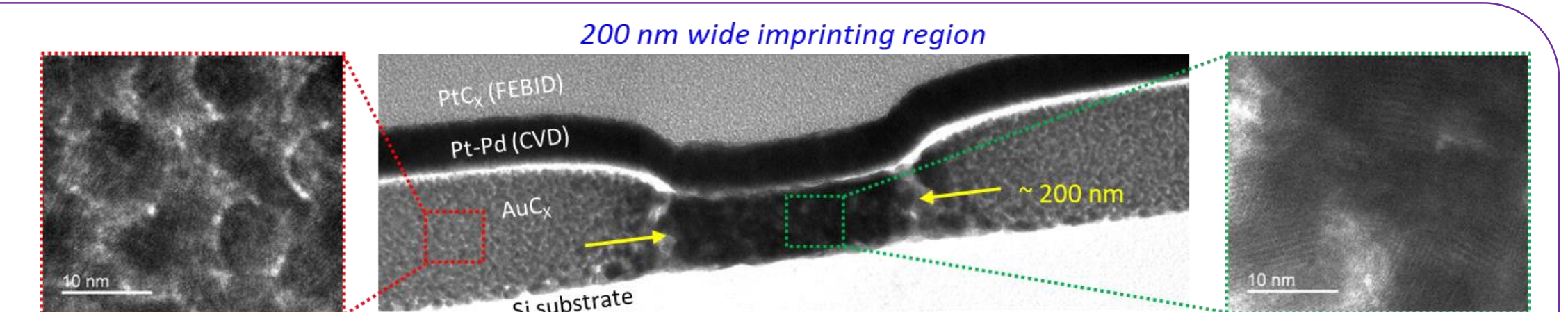


Figure 11: HR-TEM grain characterization revealed highly crystalline material at the 200 nm wide imprinted (purified) region.

### Chemistry

- Nominally pure Au in purified areas

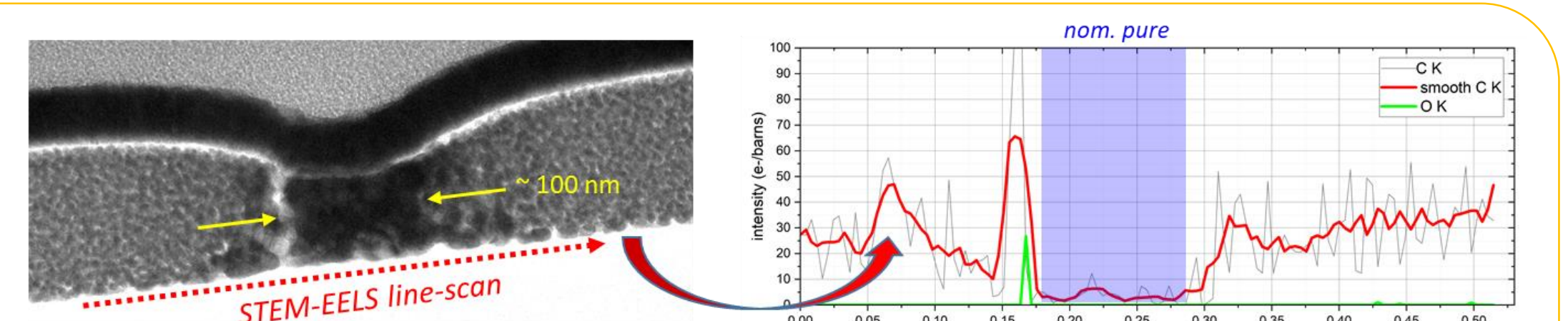


Figure 12: STEM-EELS line scans revealed a defined transition from carbon-containing, as-deposited material to the nominally pure Au imprinted regions.

### Resolution

- Trapezoidal shape
- Line width of 35 nm (FWHM)

single line with beam diameter ~ 25 nm (FWHM) @ 1 nA

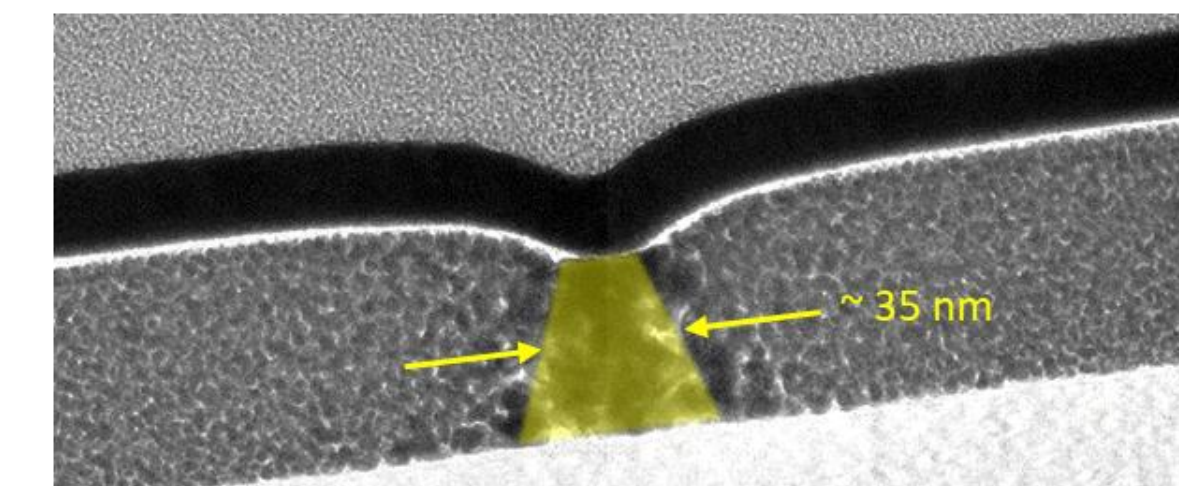


Figure 13: TEM image of single-line purification. The shape of the purified areas corresponds to the beam interaction volume.

## Conclusion

Functional Imprinting is the localized modification by electron beam irradiation of deposits fabricated via Focused Electron/Ion Beam Induced Deposition. For changing the local functionality a focused electron beam was used either under vacuum conditions (Electron Beam Curing) or under low-vacuum water atmosphere (Purification). Both approaches were presented and then locally applied on FEBID deposits. The local Electron Beam Curing leads to an energy-dependent bending effect of freestanding walls. Local Purification revealed crystalline and nominally pure Au areas with a line width below 40 nm.

## Acknowledgements

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