The FIB-SEM as 3D Nanoprinter
Overview of the Activities in Graz

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Introduction

3D printing and additive manufacturing are important areas in research and development. While 3D printing at the macro-scale down to the micro-scale has found its way to industry, real 3D printing of nanoscale objects is still a challenging task (Fig. 1). Focused Electron/Ion Beam Induced Deposition in FIB-SEM Microscopes allows the controlled direct-write fabrication of 3D nano-objects with unique advantages in terms of feature size, design complexity, minimal substrate demands, and possible materials / functionalities.

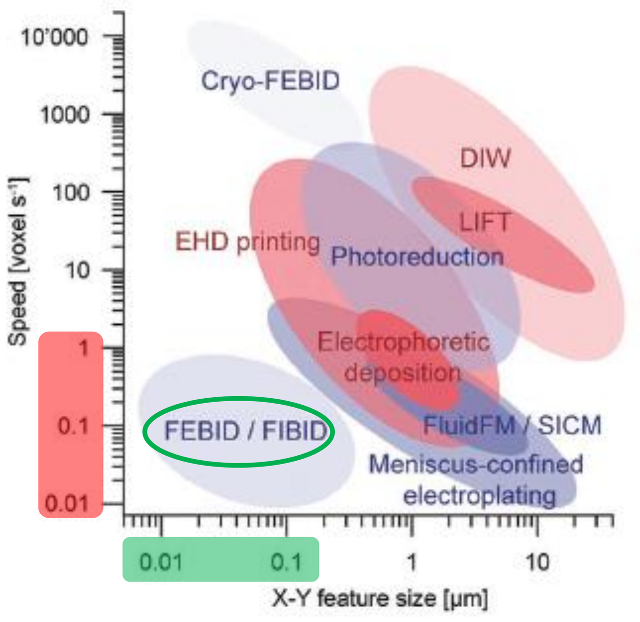
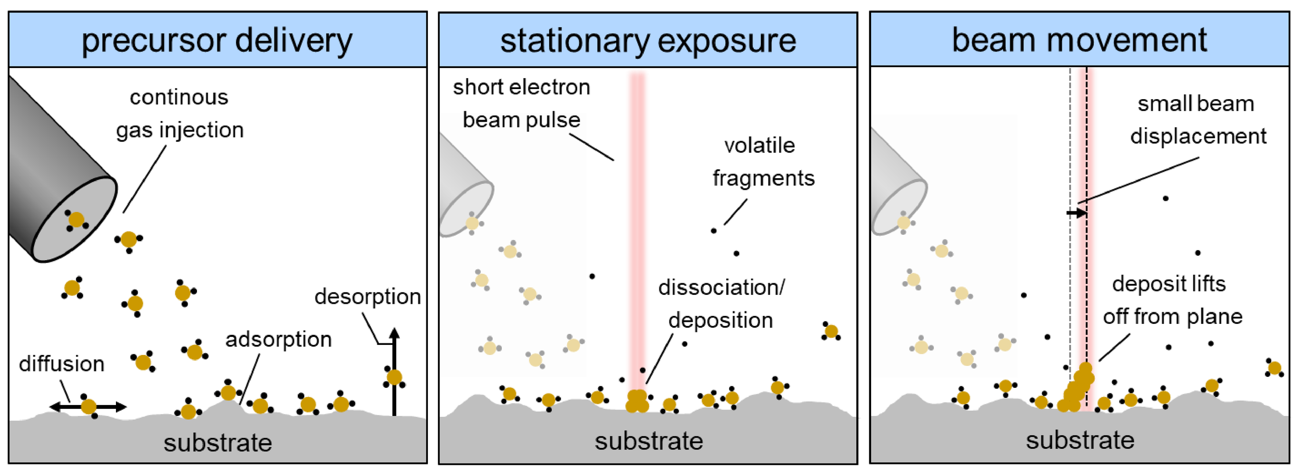


Figure 1: Comparison of additive manufacturing techniques of metal structures at the micrometer scale [1]

The 3D Nanoprinting Technique: 3D-FEBID

To grow freestanding 3D wires via 3D-FEBID (Focused Electron Beam Induced Deposition, Fig. 2), a gaseous precursor is continuously injected inside a FIB/SEM vacuum chamber and locally immobilized by electron stimulated dissociation of surface adsorbed precursor molecules.



By moving the beam at low scan velocities (~ tens of nm/s) the nanowires lift-off from the substrate.

Figure 2: The principle of the 3D-FEBID process for the fabrication of freestanding wires[2]. The electrons dissociate the adsorbed precursor and locally immobilize fragments. The stationary pulse duration (dwell time) and the beam displacement (point pitch, Δx) determine the inclination angle of the nanowire.

Research Areas Related to FEBID at the TU Graz

At the FELMI-ZFE we currently address different aspects of 3D-FEBID:

Shapes

We explore different geometries from planar (2D) deposits over bulky 3D-objects towards real, freestanding 3D. For the latter, focus is put on the optimization of meshed- and closed-structures but also their combinations.

Applications

We explore and evaluate 3D-FEBID concepts such as 3D NEMS resonators, plasmonics, scanning probes and others.

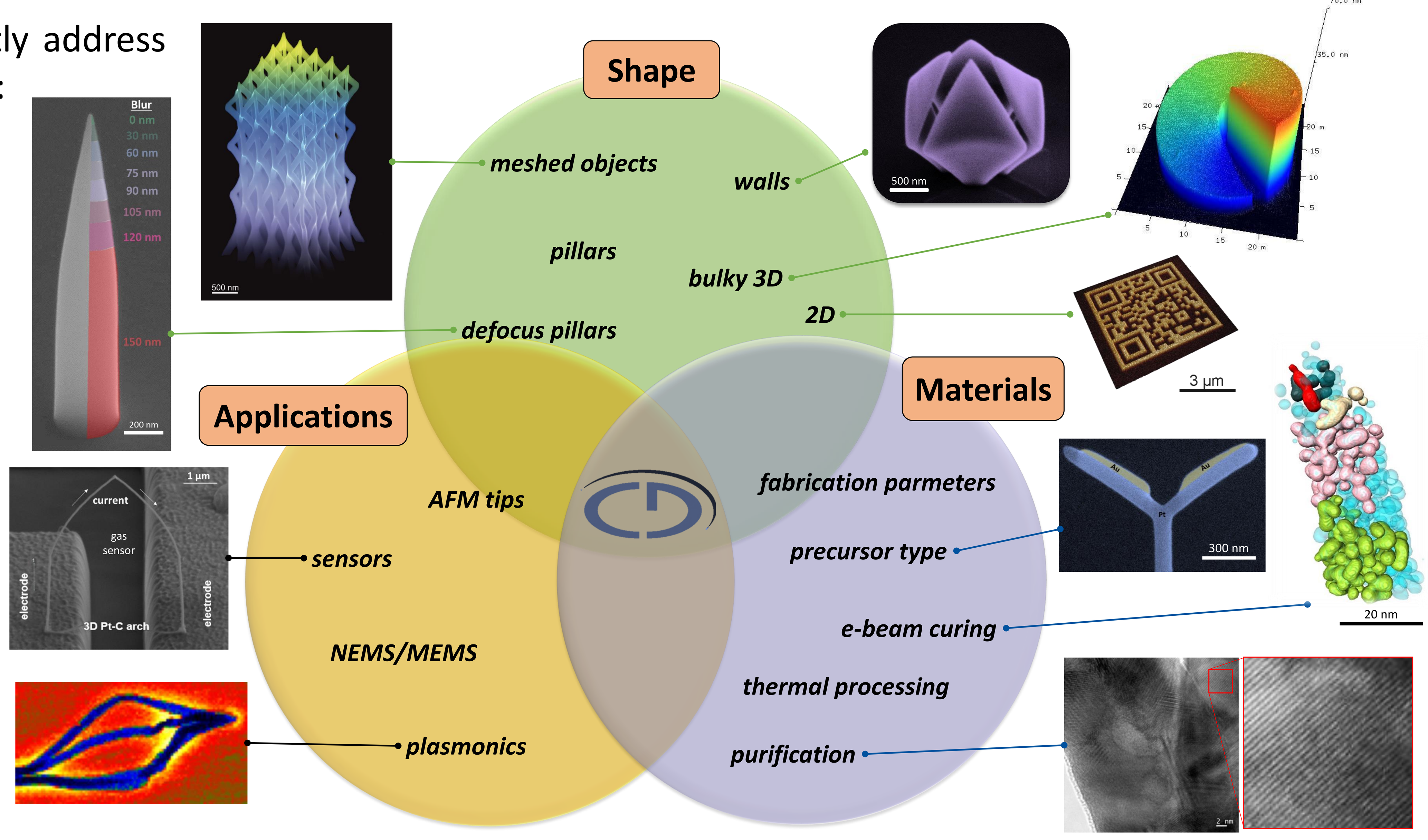


Figure 3: Research areas at TU Graz related to Focused Electron Beam Induced Deposition (FEBID) and in particular to 3D-FEBID.
Shape: Special shaped pillars (defocus pillar)[3], nano-sponge (meshed objects)[4], semi-closed petals (walls)[5], spiral phase plate (bulky 3D)[6], FEBID QR-code (2D).
Materials: Multi-material deposition (precursor type), TEM-tomography of cured FEBID pillar (e-beam curing)[7], freestanding Au- nanowires (purification)[4].
Applications: plasmonic active 3D object (plasmonics)[4], NEMS resonator-bridge for gas sensing (sensors)[8].
The fundamental research on 3D-nanoprinting in the FIB are combined to develop advanced probes for Atomic Force Microscopy (AFM) in the *Christian Doppler Laboratory*.

Materials

The material properties of the deposits can be optimized by variation of precursor/beam/process parameters and by applying different post-treatment procedures.

The application of 3D-FEBID for novel **AFM tips concepts** is explored in a dedicated project: *Christian Doppler Laboratory for Direct-Write Fabrication of 3D Nano-Probes.*

Conductive AFM (CAFM)

In C-AFM, a conductive AFM tip scans the surface to map local changes in the conductivity. With 3D-FEBID, a hollow PtC_x cone is deposited at the tip region onto an electrode of a cantilever and post-processed for transfer in fully metallic materials. The absence of any coating provides an excellent tip radius (<10 nm) as needed for high-resolution AFM images.

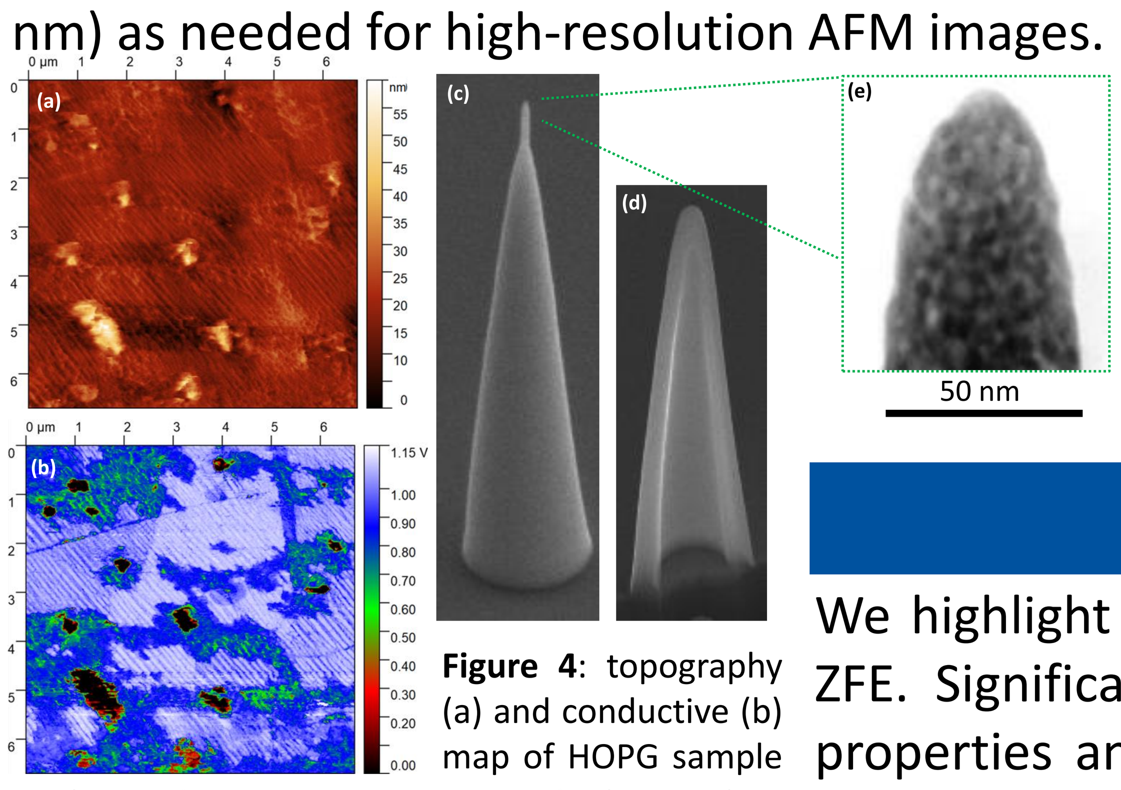


Figure 4: topography (a) and conductive (b) map of HOPG sample with conductive precipitates and Sb-particles. Hollow Pt cone (full (c) and FIB-cut (d)). (e) TEM image of the purified high-resolution tip.

Magnetic Force Microscopy (MFM)

Magnetic stray fields perpendicular to the surface can be measured in Magnetic Force Microscopy by a magnetic tip and a two-pass AFM technique. 3D-printed Co_3Fe cones show superior results compared to coated commercial tips due to the small tip radius.

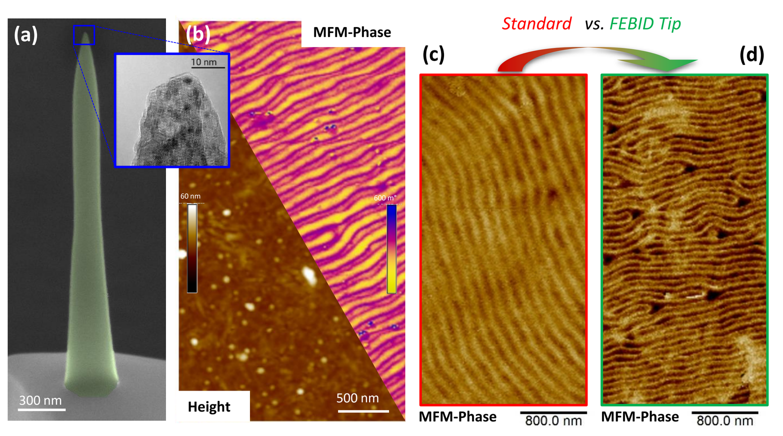
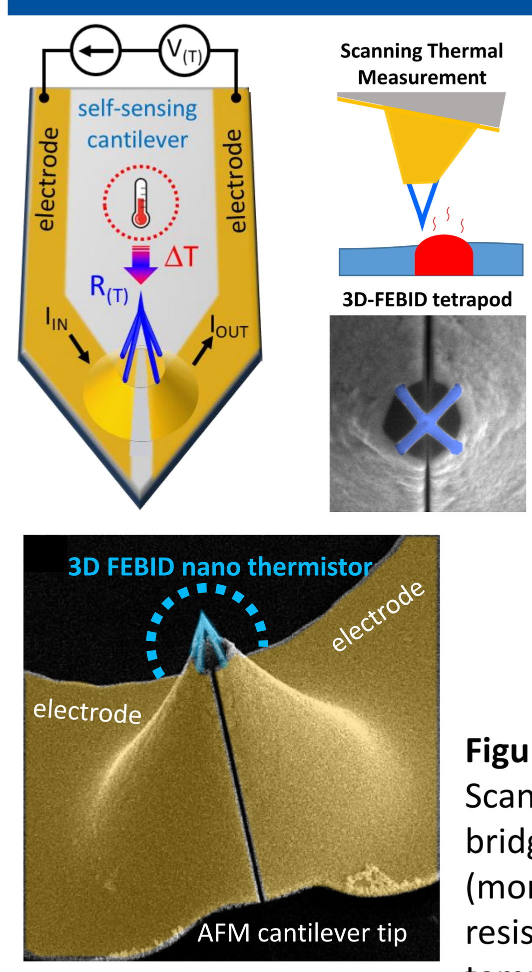


Figure 5: Magnetic Co_3Fe cone as AFM tip (a, inset shows a TEM image of the tip apex) to map the height and magnetic properties (b) of a Co/Pt multilayer sample. (c) and (d) show a comparison of a standard MFM tip with a FEBID tip.

Scanning Thermal Microscopy (SThM)



For measuring the local temperature, a PtC_x tetrapod is deposited between two, pre-structured electrodes. An electrical current is send through the small nano-bridge, which quickly changes its resistance as function of local surface temperatures.

Figure 6: 3D-FEBID based concept of Scanning Thermal Microscopy, where a bridge structure probes the surface (morphology and temperature), whereas the resistivity varies with the local temperature.[9]

The resistivity of the 3D-printed nanobridge sensitively depends on the local substrate temperature (NTC), allowing fast and reversible temperature sensing.

Conclusion

We highlight the research activities on 3D nanoprinting via FEBID at the FELMI-ZFE. Significant effort were put on expanding the shape capabilities, material properties and applications. For the latter aspect we presented advanced AFM tips developed in the Christian Doppler Laboratory for direct-write fabrication of 3D nanoprobes for their usage in C-AFM, MFM and Scanning Thermal Microscopy.

References

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