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Introduction

3D nanoprinting using focused electron beams has made major progress in recent years. Most of the initial problems such as reproducibility, ease of use, material properties, and deposition speed have now been solved or addressed in the meanwhile^[1]. By that, 3D-FEBID became an attractive method for applications where direct-writing of three-dimensional nano-objects is unavoidable. One area of such applications is the defined tip fabrication for scanning probe microscopy^[2], which enables advanced measurement modes beyond simple morphology.

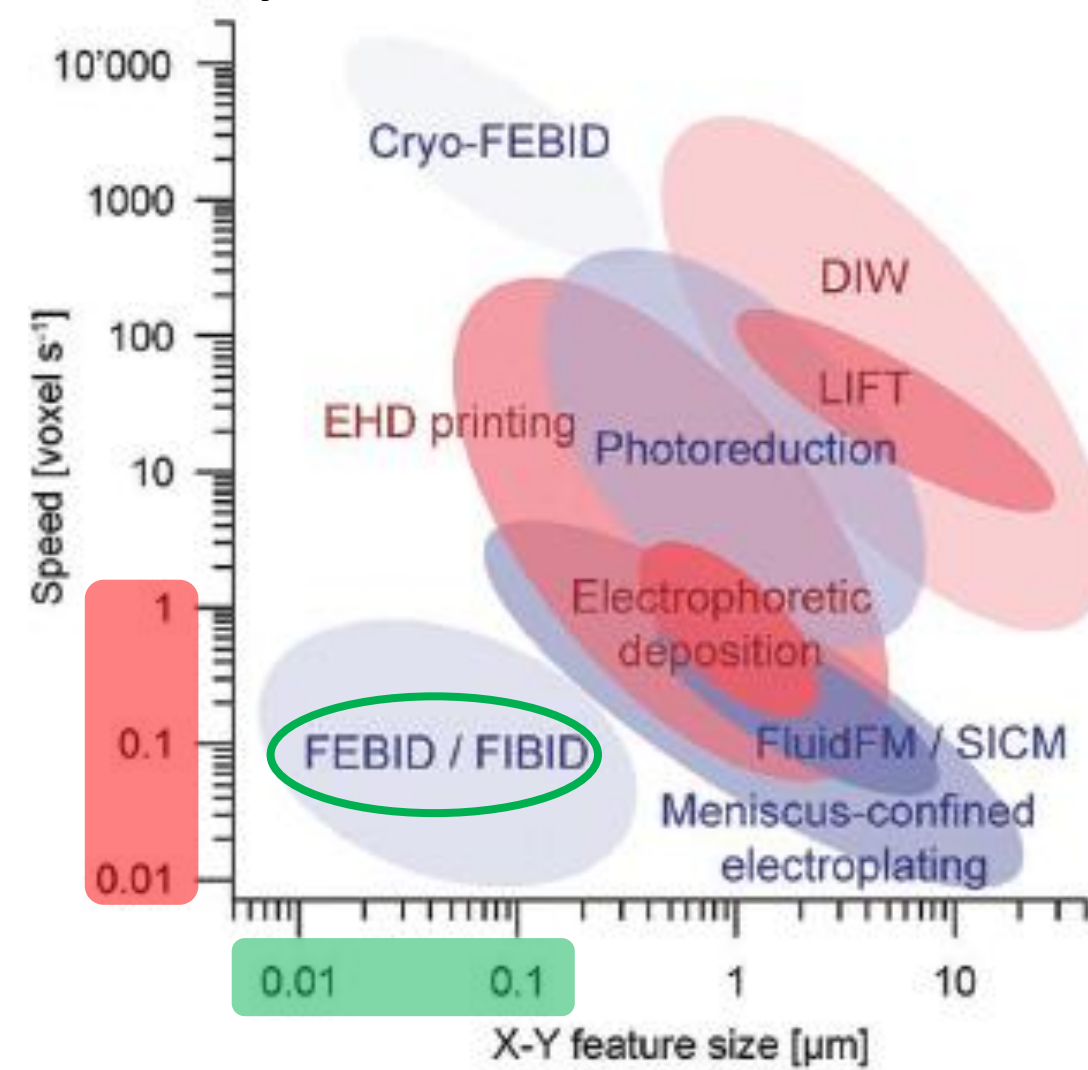


Figure 1: Comparison of additive manufacturing techniques of (sub-)micrometer 3D metal structures.^[3]

Advantages of 3D-FEBID

- + Maskless, direct-write in a single step process
- + Small and variable wire dimensions down to 10 nm
- + Complex 3D shapes thanks to patterning flexibility
- + Possible on challenging surface morphologies
- + Low demands concerning substrate materials
- + Minimal temperature rise
- + No unwanted sputtering
- + No unwanted material implantation in the substrate and the deposit
- + Printing of many materials and functionalities

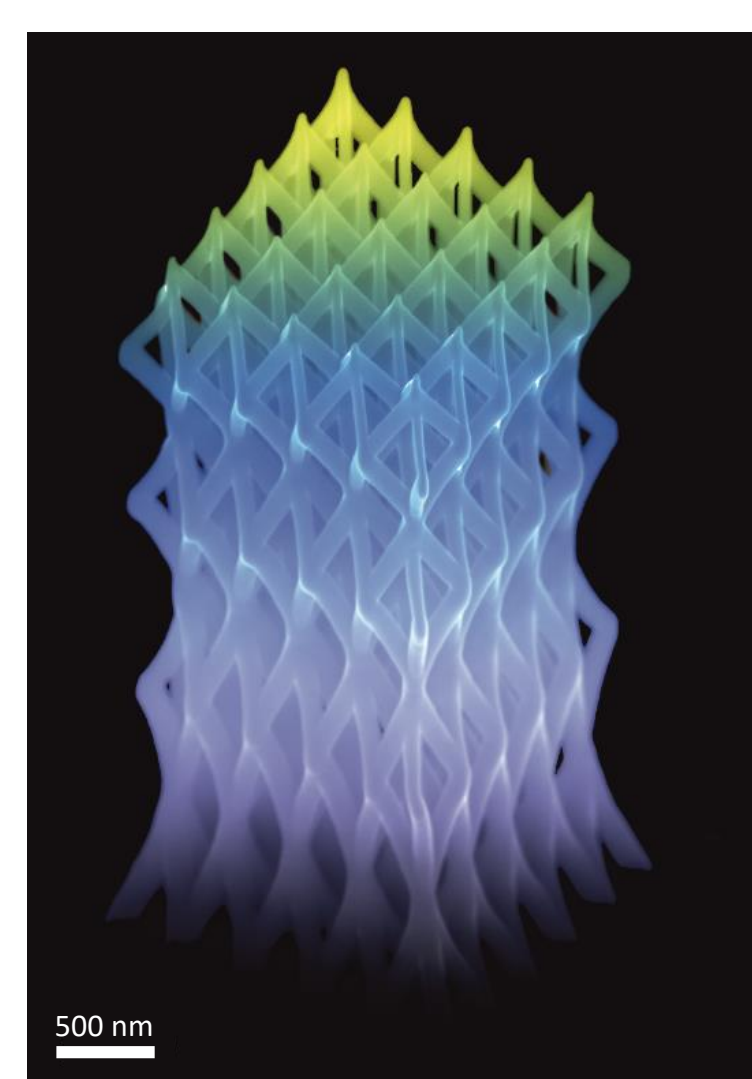


Figure 3: 3D-FEBID PtC sponge on a Si surface^[4].

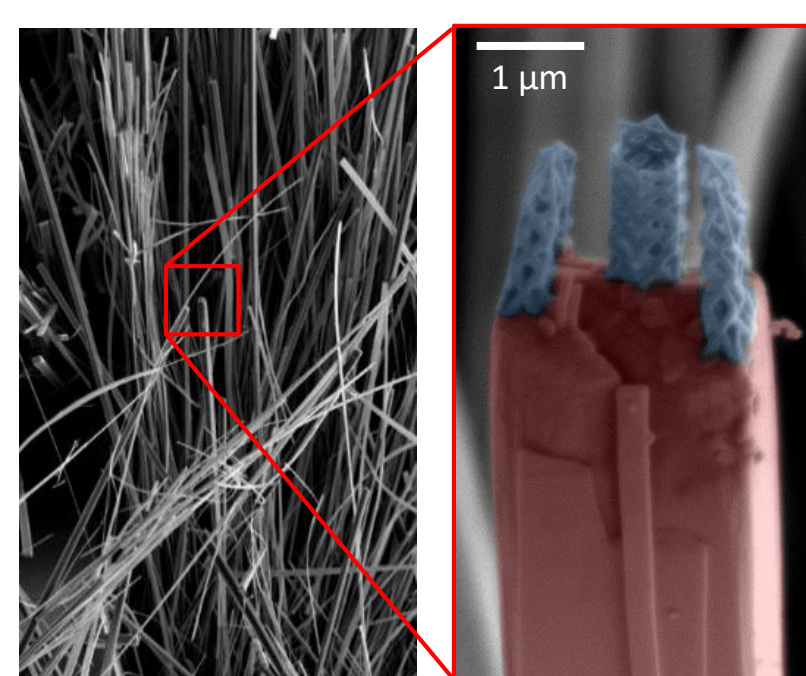


Figure 4: mineralic wires (left) as an example of a challenging surface topography for nano-fabrication^[4]. In 3D-FEBID one pinpoint the area of deposition precisely as shown by the 3D-towers on one of the wires (right).

Magnetic Force Microscopy (MFM)

Magnetic stray fields with components perpendicular to the surface can be measured via Magnetic Force Microscopy (MFM) by magnetic tips and two-pass AFM techniques. Using Co₃Fe precursor, the cantilever can be equipped with solid magnetic cones, which show superior resolution compared to commercial coated tips due to the small tip apexes.

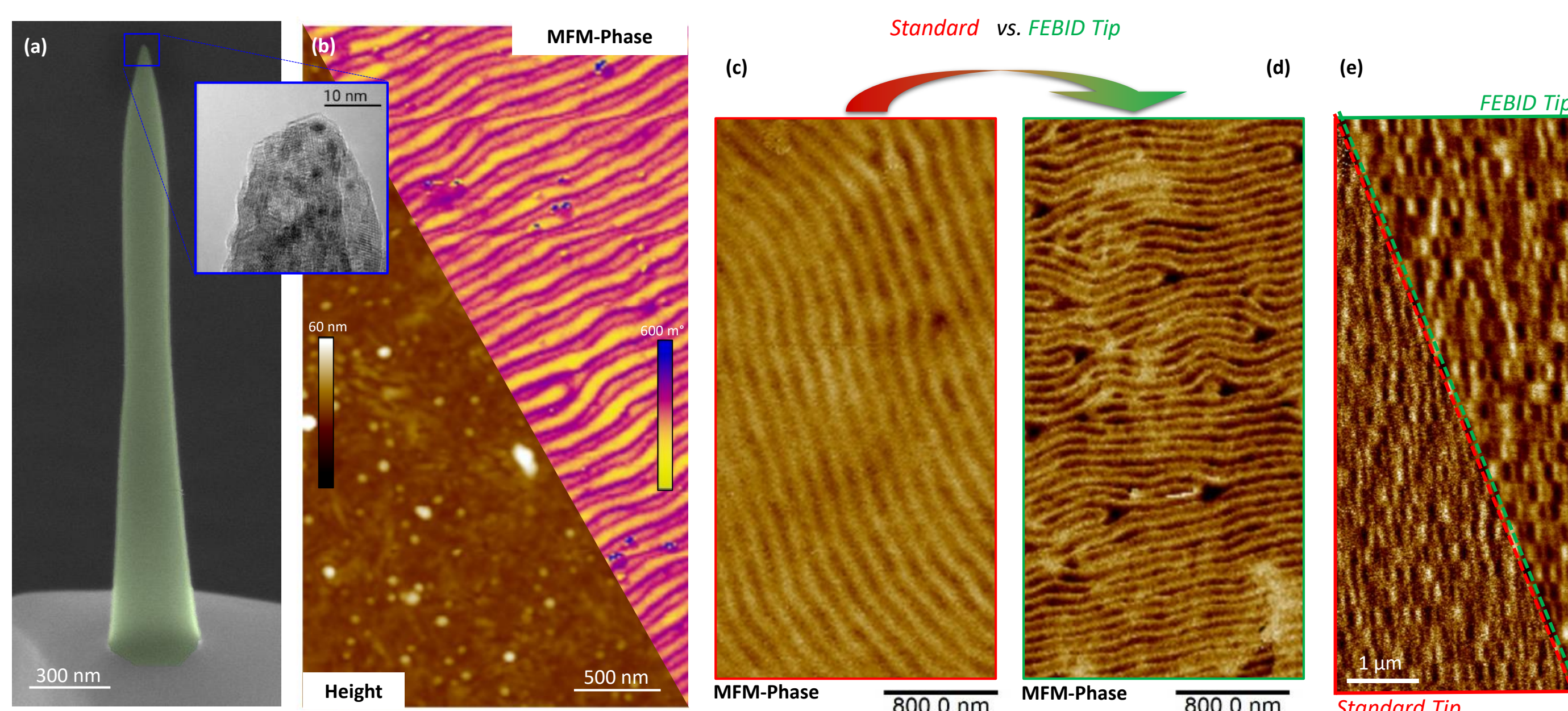


Figure 5: Magnetic Co₃Fe cone as AFM tip (a, inset shows a TEM image of the tip apex) to map the height and magnetic properties (b) of a Co/Pt multilayer sample. (c) and (d) show a comparison of a standard MFM tip with a FEBID tip. (e) MFM image showing the magnetization pattern of a Hard Disc Drive measured with a standard tip (red) compared to a FEBID tip (green).

3D nanoprinting by Focused Electron Beam Induced Deposition is a flexible direct-write technology for complex 3D-objects. One field of application for this additive manufacturing method is the modification of AFM cantilevers. Beyond simple evaluation of surface morphology, we here demonstrated three advanced AFM measurement modes, using special 3D-FEBID nano-tips: (1) a hollow Pt cone for Conductive AFM, (2) a solid Co₃Fe cone for Magnetic Force Microscopy, and (3) a tetrapod structure for Scanning Thermal Microscopy. In addition to nanofabrication details we showed AFM measurements with those tips and compared their performance with commercial AFM tips.

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.

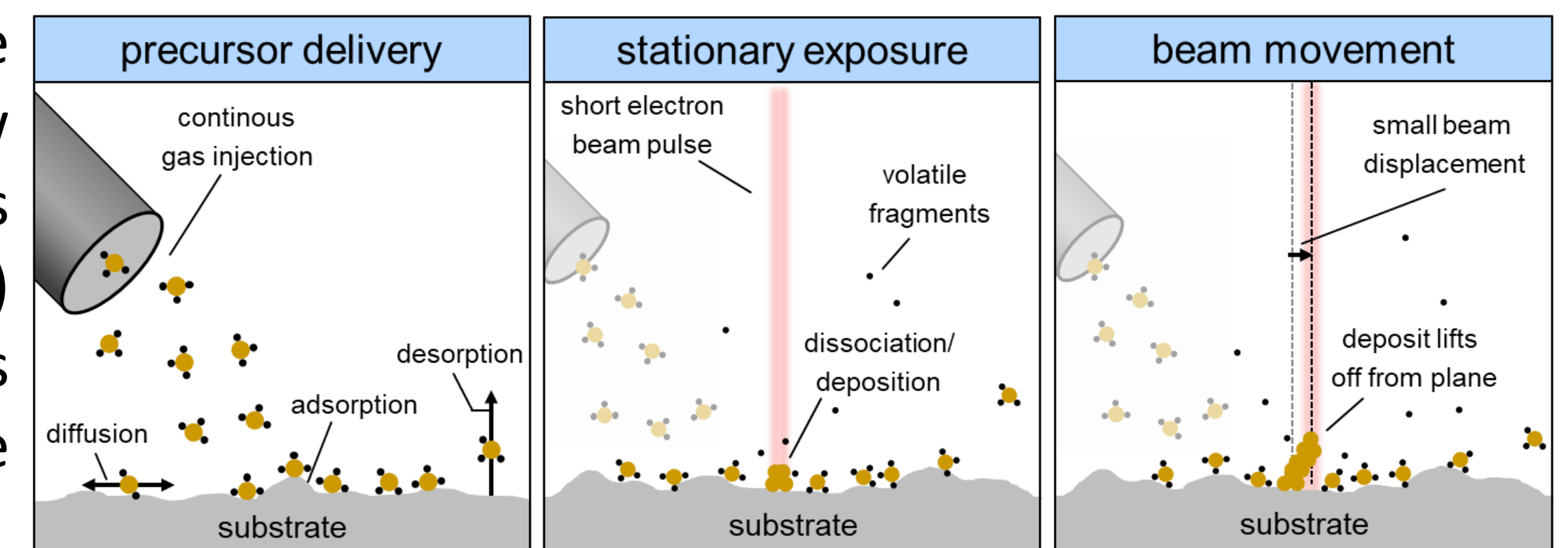


Figure 2: The principle of the 3D-FEBID process for the fabrication of freestanding wires^[1]. The electrons dissociate the adsorbed precursor and locally immobilize fragments. The stationary pulse duration (dwell time) and the beam displacement (point pitch, Δx) determine the inclination angle of the nanowire.

Conductive AFM (C-AFM)

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 a pre-structured electrode of a self-sensing cantilever and

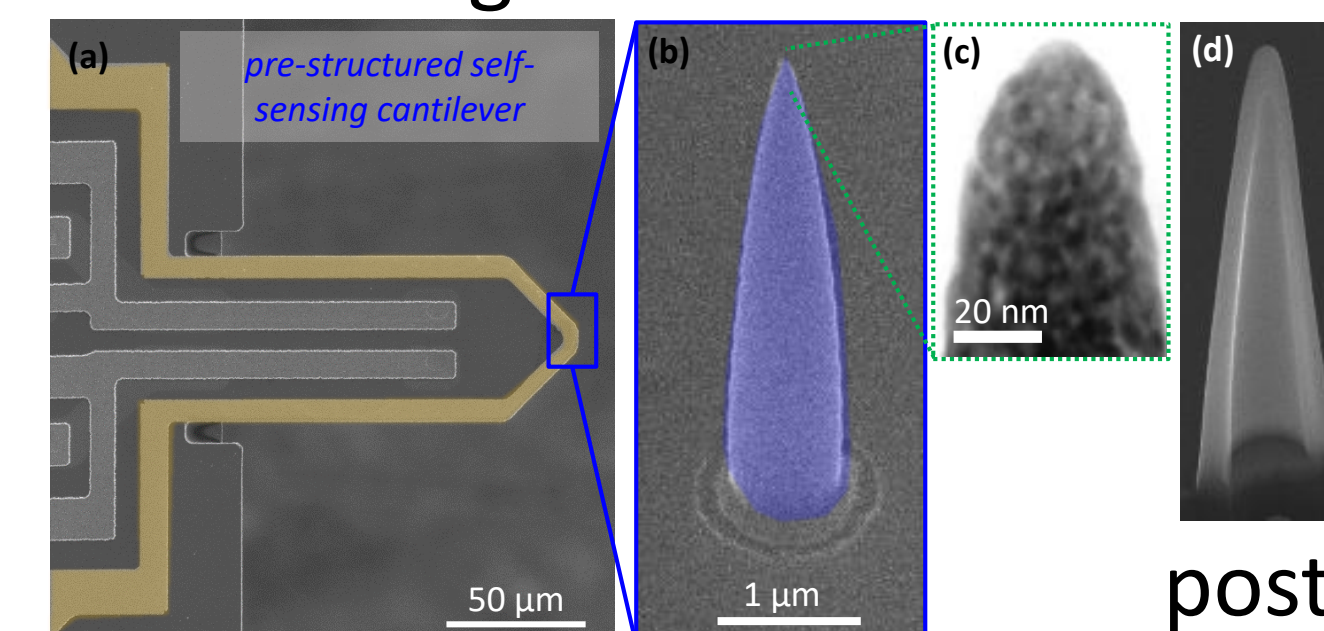


Figure 5: (a) SEM image of self-sensing cantilever platform. (b) Hollow PtC cone. (c) TEM image of tip apex after material purification.

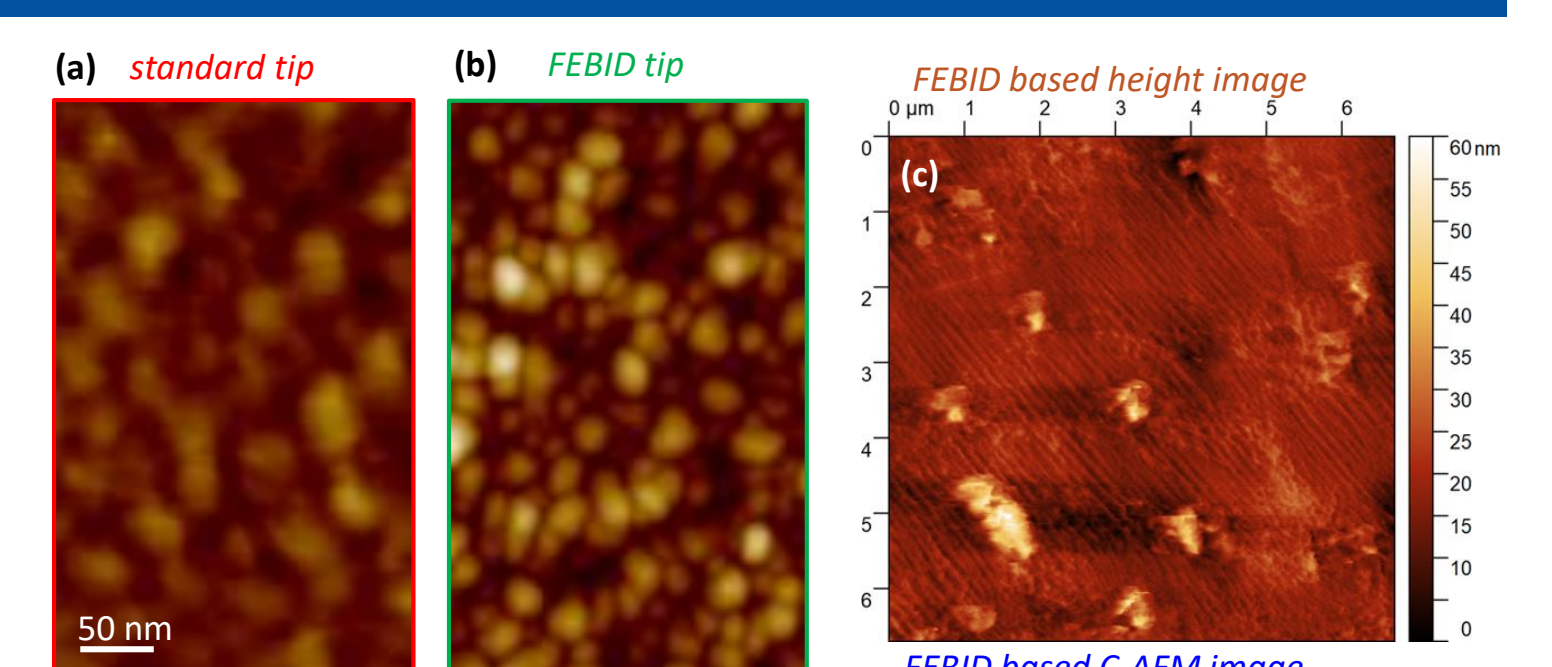


Figure 6: Lateral resolution of a standard C-AFM tip (a) compared to a FEBID tip (b). Topography (c) and conductive (d) map of HOPG sample with conductive precipitates and Sb-particles.

post-processed for transfer into fully metallic materials. The absence of any coating provides excellent tip radii (<10 nm) as needed for high-resolution AFM images.

Scanning Thermal Microscopy (SThM)

For mapping the local temperature, a PtC_x tetra-pod is deposited between two, pre-structured electrodes^[5]. An electrical current is sent through the small nano-bridge, which quickly changes its resistance as function of local surface temperatures. The resistivity of the 3D-printed nanobridge

sensitively depends on the local substrate temperature (NTC), allowing fast and reversible temperature sensing.

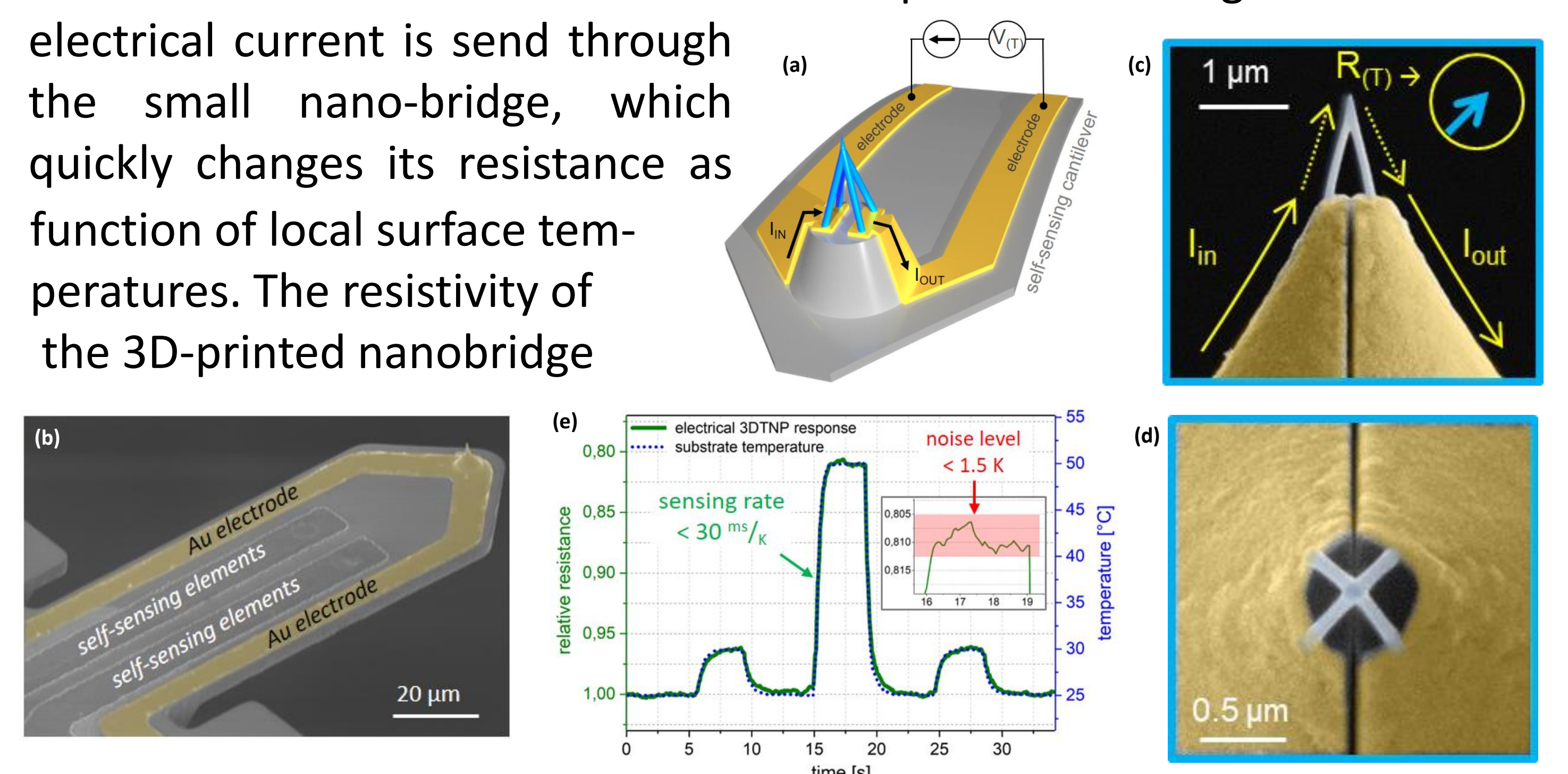


Figure 8: 3D-FEBID based concept of Scanning Thermal Microscopy (a), where on a self-sensing cantilever (b) Au electrodes are split at the tip region. The gap is then bridged via 3D-FEBID by a PtC tetrapod (c side view, d in top view). With the small-volume tip in contact with the surface the resistivity varies with the local temperature, allowing temperature sensing rates faster than 30 ms/K.^[5]

References

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