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## The FIB as 3D Nanoprinter – Overview of the Activities in Graz

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Focused particle beam microscopes are versatile tools as they allow nanofabrication in subtractive (ion beam milling, chemically assisted etching via ions or electrons) as well as in additive ways. For the latter, precursor gases are introduced by a gas injection system and locally immobilized by the focused particle beams. Those techniques, called Focused Electron / Ion Beam Induced Deposition (FEBID/FIBID), allows the deposition of nanoscale objects from different precursor materials even on extreme surface topographies and complement situations were alternative nanofabrication technologies run into their limitations (e.g. resist based lithography). Beyond planar and bulky objects, 3D printing of complex architectures becomes possible by a thoughtful control of the particle beam, leveraging both techniques into the status of a real 3D-nanoprinter [1].

In this contribution we highlight the research activities at the FELMI-ZFE in Graz (Austria), which are centered around 3D nanoprinting via FEBID. We line out actual challenges of this emerging technology on three frontiers (Fig. 1): (1) materials, (2) structure/geometries and (3) applications. For each area, we demonstrate possibilities, recent progress and remaining challenges. Furthermore, we show several applications, where such 3D-FEBID structures are used. A dedicated section presents the activities of the Christian Doppler Laboratory that focus on the direct-write fabrication of nanoprobes via 3D-FEBID with an industrial relevance. Here, we modify the tip region of Atomic Force Microscopy (AFM) cantilever with FEBID deposits [2] to enable advanced AFM modes such as conductive AFM, magnetic force microscopy or scanning thermal microscopy [3] (Fig. 2).

[1] R. Winkler et al.; *3D nanoprinting via focused electron beams*. J. Appl. Phys. (2019), 125, 210901

[2] H. Plank et al.; *Focused Electron Beam-Based 3D Nanoprinting for Scanning Probe Microscopy: A Review*. Micromachines (2019), 11, 48.

[3] J. Sattelkow et al.; *Three-Dimensional Nanothermistors for Thermal Probing*. ACS Appl. Mater. Interfaces (2019), 11, 22655

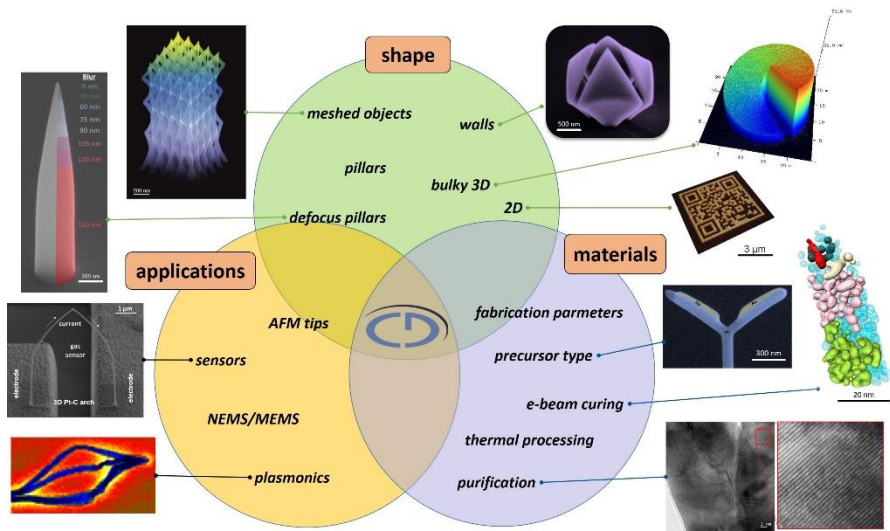


Fig. 1: Actual research areas on 3D-nanoprinting via Focused Electron Beam Induced Deposition addressed at the TU Graz, with a focus on direct-write of AFM nanoprobes.

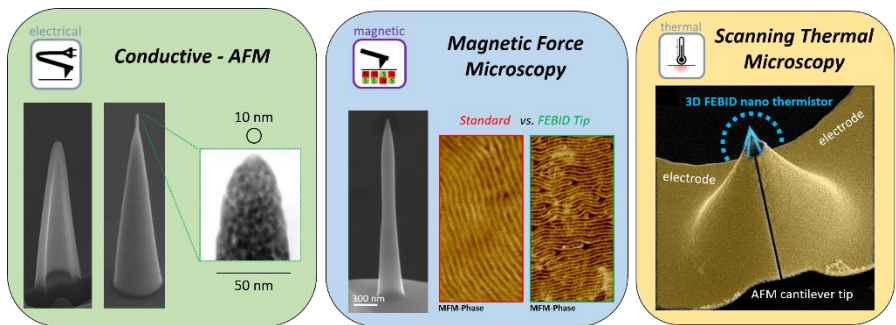


Fig. 2: Special 3D-FEBID nanoprobes for advanced AFM measurements (C-AFM, MFM, SThM), developed in the Christian Doppler Laboratory in cooperation with GETec Microscopy and Quantum Design Microscopy.