3D-Nanoprinting of Functional and Freestanding Structures via Electron Beams: an Application Perspective

R. Winkler[a,b], J. Sattelkow[a,b], H. Plank[a,b]
(a) Institute of Electron Microscopy and Nanoanalysis, Graz University of Technology, 8010 Graz, Austria
(b) Graz Centre for Electron Microscopy, 8010 Graz, Austria
robert.winkler@felmi-zfe.at

J.D. Fowlkes[c,d,e], P.D. Rack[c,d,e]
(c) Center for Nanophase Materials Sciences, Oak Ridge National Laboratory, Oak Ridge, TN 37831
(d) Department of Materials Science & Engineering, The University of Tennessee, Knoxville, TN 37996
(e) The Bredesen Center for Interdisciplinary Research and Graduate Education, The University of Tennessee, Knoxville, TN 37996

Where 3D-printing meets the ongoing trend for miniaturization of structural elements, novel direct-write nanofabrication techniques are in demand. Focused Electron Beam Induced Deposition (**FEBID**) is a promising candidate as it allows the fabrication of freestanding geometries with structure sizes at the nanoscale. Furthermore, these 3D architectures can have various functionalities and can be printed on almost any substrate material and morphology in a single-step process.

Based on strong progress in recent years, highly complex 3D-arcitectures (Figure 1) with individual branch diameters down to 20 nm can be realized. Furthermore, precision, predictability and reproducibility have been dramatically improved[1,2], which opens up new opportunities for advanced applications in research and development.

In this contribution, we first introduce the basic principles of 3-dimensional printing via FEBID (**3BID**). In the following, we present a variety of 3BID based proof-of-principle studies, including 3D plasmonics[2] and thermal nano-probes (Figure 2). Furthermore, we reflect on application ideas using magnetic, mechanical and optical properties to indicate the high potential of this currently unique nanofabrication technique. We close the contribution by an overview of remaining challenges and an outlook on further activities.

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(1) Fowlkes, J. D.; Winkler, R.; Lewis, B. B.; Stanford, M. G.; Plank, H.; Rack, P. D. Simulation-Guided 3D Nanomanufacturing via Focused Electron Beam Induced Deposition. *ACS Nano* **2016**, *10*, 6163–6172.

(2) Winkler, R.; Schmidt, F.-P.; Haselmann, U.; Fowlkes, J. D.; Lewis, B. B.; Kothleitner, G.; Rack, P. D.; Plank, H. Direct-Write 3D Nanoprinting of Plasmonic Structures. *ACS Appl. Mater. Interfaces* **2017**, *9*, 8233–8240.

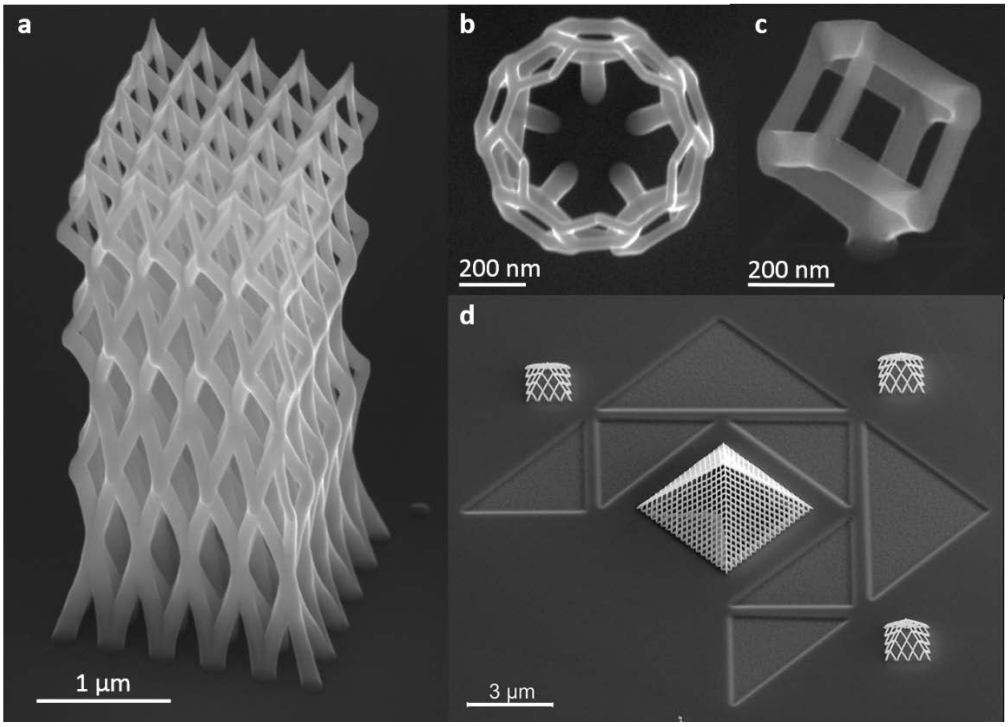

Figure 1: direct-write 3D nano-printing of meshed-like Platinum-Carbon 3D-nanoarchitectures: (a) sponge tower[2], (b) open Buckyball[2], (c) i-cube[1], (d) 3BID-model of the glass pyramid of the Louvre in Paris on a FIB-pre-structured silicon substrate[2]. All images are SEM side views except (b), which is imaged from top.

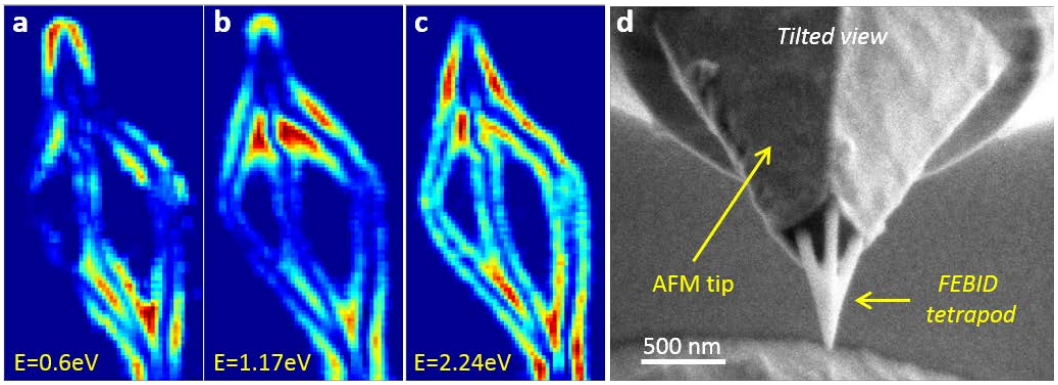

Figure 2: applications for 3BID structures: (a-c) a freestanding, pure gold 3D-geometrie, exhibiting plasmon resonances imaged by STEM-EELS maps[2], (d) FEBID-tetrapod fabricated on an AFM tip, acting as a scanning thermal probe.