Mechanical Properties of 3D Nanostructures Fabricated via Focused Electron Beam Induced Deposition

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With the recent introduction of controlled 3D nano-printing, based on focused electron beam induced deposition (FEBID)[1], an entirely new range of applications comes within reach whose fabrication is extremely challenging or even impossible with alternative techniques. Beside the 3D aspect itself, the combination with different materials contains huge potential for optical[2], electronic, magnetic, thermal or mechanical applications with 3D feature sizes down to the lower nanoscale. Apart from scientific fields of interests, the generic character of this 3D nano-printing approach attracted the attention of industry as flexible on-demand modification tool. In more detail, we currently aim on the integration of Pt based 3D nano-bridges on atomic force microscopy (AFM) self-sensing cantilevers with the goal of high-resolution 3D thermal nano-probes (Fig. 1). Beside the inherent thermoelectric response of Pt, acting as transducer element, the small active volumes and end radii down to 5 nm are essential if aiming on fast thermal response and high-resolution capabilities, respectively. However, when operated as AFM tip, the mechanical stability in XYZ is of essential importance and requires a detailed optimization prior to any real application. Following that motivation, this study focuses on nano-mechanical peculiarities of Pt based, freestanding 3D nano-architectures fabricated via FEBID. A combined approach of finite element simulation, AFM based force spectroscopy and real-time imaging via scanning electron microscopy is used to 1) reveal individual morphological / mechanical peculiarities during force load; 2) adapt the FES model to gain comprehensive understanding of their origins and 3) optimize the 3D geometries towards highest spatial stability. In detail, we discuss the unexpectedly strong influence of non-straight side branches as well as the consequences of fabrication mismatches on the lowest nanoscale, leading to non-linear mechanical behavior and morphological twisting, respectively (Fig. 2). The combined outcome of these efforts are AFM proven 3D nano-probes, which pave the way towards fully functional, thermal high-resolution probes.

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[1] Fowlkes J.D. et-al (2016). *ACS Nano*, 10 (6), 6163.

[2] Winkler R. et-al (2016). *ACS Appl. Mat. Interf.*, DOI: 10.1021/acsami.6b13062

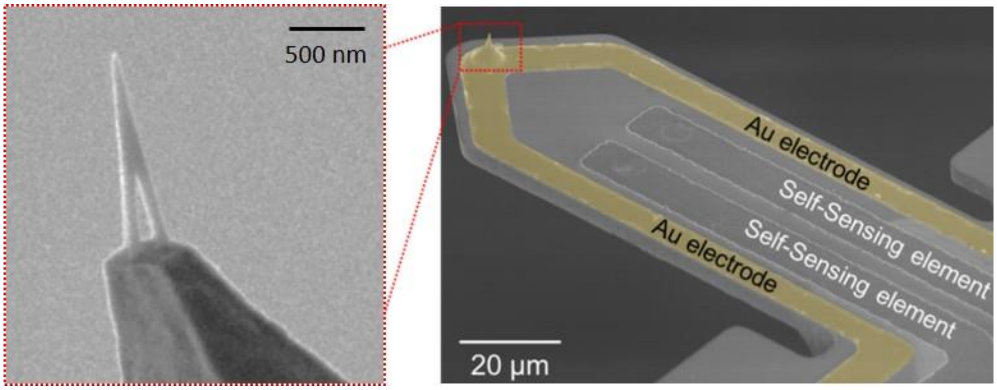

Figure 1: FEBID based 3D nano-printing of freestanding tetra-pods with branch diameters < 70 nm (left) on pre-structured self-sensing cantilever for application in atomic force microscopes.

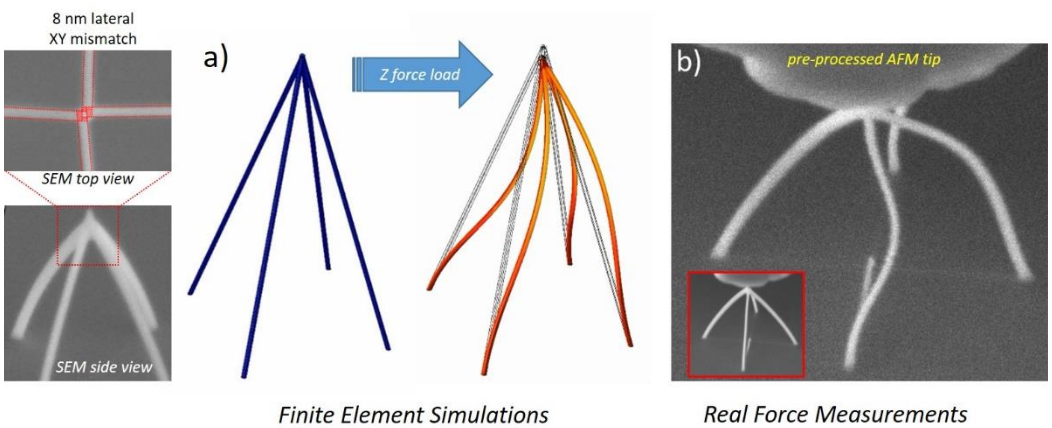

Figure 2: Morphological consequence of fabrication inaccuracy on the lower nanoscale. The 3D tetra-pods reveal a lateral mismatch of less than 8 nm in XY at topmost areas (see SEM images in a). The consequence is a reversible, morphological twisting effect during vertical force loading predicted by finite element simulations (a) and confirmed by combined force spectroscopy and SEM investigations (b). Note, the deformation is reversible (bottom left Inset).