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3D Nanoprinting of Electrical AFM Nanoprobes

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Along other Scanning Probe Microscopy techniques Atomic Force Microscopy (AFM) has evolved into a widely used characterization technology at the micro- and nanoscale. Highest lateral resolution is enabled using very sharp probes which are scanned across a sample. This approach allows to surpass Abbe's limit of diffraction and has thereby paved the way towards new insights and innovative applications in research and development. In addition to high resolution topo-graphical imaging, AFM enables simultaneous mapping of surface properties such as mechanical, electrical, chemical, magnetic or thermal, with nanometer resolution. Advanced operation modes, however, rely on functionalized probes. Commonly, standard Si tips are coated with relevant materials to induce a desired functionality. Disadvantages are a larger apex radius, reducing resolution capabilities, and the risk of delamination effects due to mechanical stress during AFM operation, which reduce or even eliminate the targeted sensitivity. Hence fully functional uncoated probes with very sharp apex radii would be desired. With its unrivaled flexibility in terms of structural delicacy, geometrical flexibility and minimal requirements to substrate material and morphology, Focused Electron Beam Induced Deposition (FEBID)[1] is perfectly suited for the fabrication of AFM probes. Post-growth treatments enable accurate tailoring of material's properties towards the intended application[2]. With this motivation in mind, we here present a Pt-based 3D hollow cone concept for application in electrical AFM modes (CAFM, EFM, KPFM). The presentation will cover the entire interlinked design and fabrication process to achieve mechanically stable probes with sub-10 nm apex radii as well as their chemical transfer into highly crystalline Pt structures preserving the mentioned shape aspects (Fig.1b). We then present AFM studies to compare the performance of our FEBID probes to commercially available probes both in terms of resolution (Fig.1c,d) and functionality (Fig.1e). Together with the fact, that those concepts are meanwhile patented in collaboration with our industrial partners, this contribution clearly shows the industrial relevance of 3D-FEBID in the area of Atomic Force Microscopy.

[1] Winkler et al, *3D nanoprinting via focused electron beams*, J. Appl. Phys. 125, 210901 (**2019**)
[2] Geier et al., *Rapid and Highly Compact Purification*, J. Phys. Chem. C 118, 14009 (**2014**)

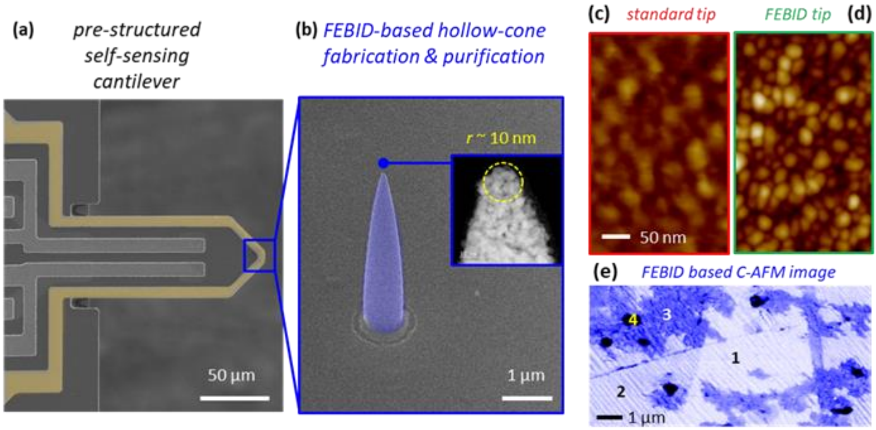

Figure 1: (a) pre-structured AFM self-sensing cantilever, which was first equipped with a PtC hollow-cone (b), further transferred into pure Pt with apex radii in the sub-10 nm regime (inset in b). (c) and (d) give a direct AFM topography comparison between commercially available C-AFM probes and the here relevant hollow-cones, respectively, which clearly shows the improved lateral resolution. (e) representative CAFM image enabling clear identification of a single-layer (1) and multi-layer graphene (2), copper oxide particles (3) and insulating Antimony particles (4) and proves CAFM applicability.